



Analyse diachronique de la fragmentation des forêts du Liban

Ihab Jomaa

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THÈSE

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It is 11:30 am, Toulouse-Matabiau, August 21 2003 the train stopped; my heart jumped into my throat; who will be my guide; my guide probably for several years but he will stamp knowledge that will never be forgotten. At the "gare" frustrated I am looking around, suddenly an ambitious sound came by me asking, "are you Mr. JOMAA". My heart got back in place; undoubtedly, gracious is he. "Truly, he is the kindest man I have ever met in my life". I still don't know exactly what it was about that moment that made me tranquil, but I do know that there was something magical about it. There was an essence, a quality of open, honest, intellectual exchange of student and teacher. In that instant, I knew I needed to know who this gentleman was, because somehow - at that moment - I knew that he would play an important role in my life. I then embarked the scientific train of a Ph.D. with a very helpful man. I trusted my feelings....

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ABSTRACT

This research fits within the scope of landscape spatial analysis of forest fragmentation with the discipline of landscape ecology. In Lebanon, accurate status of the forest cover swims in deep vagueness. Landscape metrics and remote sensing were used to investigate spatial forest changes. Forest investigations were performed broadly for the entire country and then in more detail on a chosen representative study area. The existed forest spatial data were first compiled in GIS environment where it was found to require amendment for their accuracy. Reuse of the source data was needed to improve forest map of 1965, which was the base source of data in this research. Remote sensing provided successive spatial information of landcover as well as forests. New thoughts were developed such as: urban encroachment rate of approaching forest areas, abiotic factors with relation to forest fragmentation, forest area loss relation to landscape indices, forests orientations, regeneration of forests, hemerobiotic state of forest patches (linear features and intrusions against forest patches), topographic complexity analysis of a forest patch, integration of topographic feature in Mean Nearest Neighbor Index and solving the problem of spatially representing juniper forests of Lebanon. Landscape indices were found to be misleading if computed on landscape constituted of coastal and inner part of Lebanon altogether. Forests area increased at the coast but fragmentation increased where forest patches become small and isolated. Oak forests of the coast largely differ in their cover density than the inner land ones. Regeneration of oaks, at the coast, requires several years where it affects image classification as it appears as complete oak forest area within a short time period. The rugged topography causes forests to remain in limited areas and sometimes in strip-like-shaped forest patches (valley-controlled forests). One third of the forests in Lebanon have roads passing across them. Road density, which we developed, could be used to add information with regard to landscape and patch level metrics. Human interferes within the forest patch leaving remotely detectable linear features with a forest patch and change forest edge causing intrusions either abrupt or smooth. These intrusions cause the appearance of gulf-like forest dents emerge from a forest patch. Topographic characteristics of a forest patch could be computed through our developed index called "Relative Number of Topographic faces. This research deals with landscape spatial analysis of forests in Lebanon while developing several new methods that open the roads for future research especially in Mediterranean forests.

Keywords: Forest fragmentation, Remote Sensing, Ikonos, Landscape metrics, Topography, Roads, Lebanon, Forest change.

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*à mon épouse Sahar,
à mes parents*

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List of abbreviations

| | |
|--------|---|
| AWMPFD | Area Weighted Mean Patch Fractal Dimension |
| BV | Brightness value |
| DEM | Digital Elevation Model |
| DN | Digital number |
| ED | Edge Density |
| EL | Edge Length |
| Freq. | Frequency |
| GIS | Geographic Information System |
| IFOV | Instantaneous Field of View |
| IPAR | Intercepted Photosynthesis Active Radiation |
| LCCS | Land Cover Classification System |
| LPI | Largest Patch Index |
| MLC | Maximum Likelihood Classification |
| MNN | Mean Nearest Neighbor |
| MPS | Mean Patch Size |
| NDVI | Normalized Difference Vegetation Index |
| PN | Patch Number |
| PsIs | Patch strip like shape |
| RD | Road Density |
| RMSE | Root Mean Square Error |
| RTF | Relative Number of Topographic Faces |
| STD | Standard deviation |
| TE | Total Edge |
| yr | year |

General Introduction



General introduction

Forest loss and the concomitant fragmentation are among the most important environmental issues that have been threatening biodiversity worldwide. Fragmentation processes could be reflected by increasing habitat isolations (Debinski and Holt, 2000; De Luis *et al.*, 2006), changing forest spatial configurations (Bélanger and Grenier, 2002; Jha *et al.*, 2005), endangering species (Collevatti *et al.*, 2001), negatively alter species richness (Gigord *et al.*, 1999) and modifying population dynamics (Watson *et al.*, 2004). Fragmentation also causes remnant vegetation patches to vary with time since excision from previously continuous forest (Turner, 1996). Since ecological integrity is a function of changes that occur in spatial or pattern configuration imposed on a landscape (Cayuela *et al.*, 2006), fragmentation breaks environmental equilibrium. Fragmentation studies stand on the growing theoretical and empirical framework that links biological processes to landscape configuration and composition.

The explicit relationship between forest fragmentation and biodiversity encouraged scientists to develop forest monitoring and spatial analysis tools. Indicators have been developed to describe landscape and forest fragmentations through quantifying changes (O'Neil *et al.*, 1988; McGarigal and Marks, 1995; Riitters *et al.*, 1997). In this respect, remote sensing and geographic information system (GIS) help to perform detailed structural characterization and quantification of landscape spatial patterns in recent decades. The combination of remote sensing, GIS and landscape spatial analysis has offered managers, conservationists and scientists the possibility of making faster decisions and conclude better results.

Mediterranean Basin countries differ widely in their forest coverage, ranging from the lowest in Egypt (0.07%) up to the highest in Portugal (41%). While in Lebanon, the latest forest cover information reveals the existence of 13% coverage (MoA and FAO, 2005a). However, some literatures estimated this cover by 8% (Abi Saleh *et al.*, 1996). This discrepancy in quantifying total forest cover is a result of using different spatial scale maps or different forest definitions (e.g. Abi Saleh and Safi, 1988; MoA and FAO, 2005b). Whichever, Lebanon appears to have average forest cover among other countries in the Mediterranean Basin.

Like many countries of long civilizations history, Lebanon is suffering from severe forest fragmentation. Pabot (1959) explained, based on years of field observations, that natural vegetations around Lebanon are under severe degradation status, because of deforestation, grazing and erosion processes. Nowadays, a faithful status of the forest cover in Lebanon is in deep vagueness, because the prevailing studies have mainly used one index for describing the forests, i.e., total forest cover change.

Landscape ecological investigations, on the other hand, offered important landscape indices that should also be considered while studying forests. Landscape metrics in Mediterranean forests could be useful in establishing a landscape-monitoring program, to detect the local drivers of biodiversity, and to improve management decisions (Schindler *et al.*, 2007).

Even though efforts to quantify patterns of landscape began in the 1980s (Krummel *et al.*, 1987; O'Neill *et al.*, 1988), their application in the Mediterranean ecosystems is considered minim. Thus, landscape spatial indices have to be tested for their eligibility in the Mediterranean and especially for predicting future changes and understanding forest behavior.

Lebanon has significant floristic diversity because of its geographical location and its high variability of abiotic conditions. In addition, the country is characterized by significant landscape diversity that is the result of topographic and physiographic nature thus a millennia of human interference. This wealth in biodiversity is at risk, because of the continuous land degradation and, especially forest fragmentation. Forests in Lebanon are being fragmented by both anthropogenic and natural causes. Nowadays, these forests are considered as fragments and residual patches.

The chaotic expansion of urban settlements and agricultural practices has exacerbated the depletion of natural resources (Talhouk *et al.*, 2001). Quarrying is also taking over the forest cover when counting 710 quarries distributed around the limited territory of Lebanon (Dar el Handassah, 1996). Studies focus on forests changes and biodiversity in Lebanon do not even mention fragmentation of forests (e.g., MoA and FAO, 2005a). Fragmentation processes are not documented where only forest mapping and the consequent total landcover change are the concern of many institutions.

Since only few fragments of different forest types remained at various altitudes around Lebanon, conservation efforts must focus on the remaining forest fragments, and more information is needed for their management. In addition, describing the pattern of forest fragmentation should be among the priorities on the road for sustainable forest use.

Lebanon is one of the countries that signed and ratified the Convention on Biological Diversity (CBD) in 1994. The CBD provides an international framework for conservation of biodiversity. By signing the CBD, Lebanon agreed to take actions in reducing the current rate of biodiversity loss by the year 2010. Achieving this target requires rapid and cost efficient methods to monitor, inform, assess and quantify changes in landcover and biodiversity.

The main question is: did we extract yet from the existing spatial data on forest in Lebanon enough information? The forest spatial information in Lebanon could be divided between maps (spatial distribution data) and descriptive discussion of a spatial perspective (vegetation levels and forest relation to geological formations). The country printed forest maps are for the years 1965, 1966, 1988 and 2005. Other spatial data could be extracted from the 1990 and the 2002 landcover maps. This quantum of the spatial data gives an impression that Lebanon is wealthy with regard to forest spatial data but this data is still incoherent. The unpleasant truth underlies behind the source of data used to obtain these maps. We should not also forget the different spatial scale and the variability that resides in authors' perspectives that adds to the differences between categorical maps. Accuracy of spatial information is also a major problem, which must be considered.

The other question is: do the existing spatial data offer the possibility to extract beneficial ecological information? Concerning forests, the existing spatial data has relatively long enough time span to start the ecological analysis. The first spatial forest data is dated back to the 1960's, where the landscape spatial patterns could largely change. The spatial configuration changes characterize these spatial patterns are one important ecological aspect.

The main objective in this research is to understand forest fragmentation for different forest types as an important landcover change process in Lebanon through:

- 1- Examining the applicability of landscape indices on forests of Lebanon
 - Forest fragmentation on landscape and class levels.
 - Detecting future changes using landscape indices.
 - Detecting forest regeneration, together with spatial pattern configuration.
 - Hemerobiotic state of forest types and each forest patch, effect of spatial configuration (investigating lineament features inside forests, human interferences and roads).

- 2- Knowing the causes of fragmentation through studying the:
 - Urban approaching forest patches
 - Transition matrices of forest patches (landcover change inside old forest patches)

- 3- Investigating the added value of remote sensing on landscape spatial configuration analysis, by using:
 - NDVI to detect regeneration of oak forests
 - NDVI to differentiate oaks in coastal and inner parts of Lebanon

- 4- Investigating the degree of connectivity between patches using topographical characteristics
 - Topographic features (number of slope gradient and aspects between patches will explain how smooth is the connectivity between patches).

- 5- Establishing a standard representation of Juniper forests that will facilitate future monitoring, and solving the discrepancies and problems facing this forest delineation and mapping in Lebanon.

This research is organized in four parts as follows:

Part I.

This part includes literature review relevant to the research topic. It is organized in two chapters:

Chapter 1 addresses the ecological problems of the Mediterranean forests, research needs and characteristics of this forest ecosystem; forests of Lebanon were also described with little history of the related studies.

Chapter 2 handles the landscape spatial pattern theories and main usages. It also explains the role of remote sensing in landscape spatial pattern analysis

Part II.

This part includes two chapters tackling the study area, materials used to accomplish this research and the methodology designed to reach the research objectives.

Part III.

This part includes the results in one chapter that handles first results for forest changes on the entire country; and then includes detailed forest analysis on a selected area of Lebanon.

Part VI.

This part first discusses the obtained results and then constructs the conclusion related to the entire work.



Part I.

Literature Review

CHAPTER 1

1. Forests and the Mediterranean

This chapter establishes an overview of literatures for utilizing *landscape spatial analysis* approaches on Mediterranean forests. The spatial characteristics of the Mediterranean landscapes and forests were clarified, with emphasis on factors affecting forest fragmentations, especially those that are rarely studied. Evolution of forests in the Mediterranean was tackled and especially in Lebanon. Knowledge on forests resources in Lebanon was brought where the importance of our research emerges. The theories behind landscape spatial analysis were thoroughly undertaken, while first important terms in landscape analysis approach (like landscape, patch, corridors, etc) were refined. This allowed us to explain the different tools related to landscape spatial analysis. Problems and difficulties related to the use of such tools (landscape metric, remote sensing) were also explained.

1. Mediterranean forests and research needs

In the Mediterranean Basin, a relatively wide range of climatic conditions occurs, from arid to humid environment (Quézel, 1985). The presence of fragmented and steep mountain slopes and profound valleys on various geological substratums multiplies the climatic heterogeneity and creates microclimatic conditions.

Mediterranean forests are heterogeneous, therefore, on their biotic specificity, which is based on the diversity of abiotic factors mainly geographical, geological, geomorphological, pedological, and bioclimatic (Quézel, 1974; Casazza *et al.*, 2005). Ecosystem processes may also be contrasting even when they are associated to the same species. For example, natural ecosystems in Lebanon face climatic and microclimatic variability within short distances. For example, *Quercus calliprinos* behaves completely different, comparing the typical Mediterranean-to-Mediterranean presteppe floristic ensembles.

In Mediterranean ecosystems, natural vegetations often consist of shrub species that grow within a matrix of herbaceous plants, mainly annuals. Mediterranean forests are divided into different vegetation groups (Quézel and Médail, 2003), such as broadleaf (evergreen and deciduous) and coniferous trees. Most of the broadleaved forests are of sclerophyllous type, which they are named differently all-around the Mediterranean regions. They are called chaparral (California), matorral (Spain), maquis (France and most of Mediterranean countries), Macchia (Italy), fynbos (South Africa), or kwongan (Southwest Australia). The degraded form of maquis is scrubland named garrigue (in France).

Since the dawn of civilization, Mediterranean forests have undergone spatial structural changes, but this process was slow, long and relatively sustainable. Recently, human-nature balance has been broken and lost. Forests are now fragile and under complete threat of extinction (Figure 1). Fragmentation of the landscapes is decreasing the chance of large forests to reestablish. It is the destiny of these forests to stay fragmented in isolated islands. Large wild animals, which require large forest areas, will probably never host this area again unless major changes occur in human policy and even though it will require a long time.

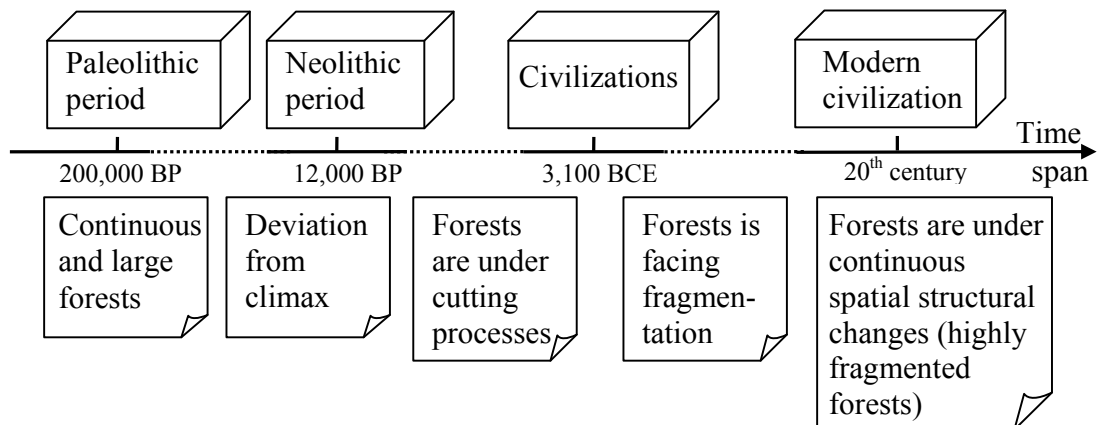


Figure 1. Mediterranean forests, long history of human interrelation (prepared in this manuscript).

Mediterranean Basin is a perfect example of strong landscape and ecosystem changes (Vogiatzakis *et al.*, 2006). A long list of human-induced changes could be drawn, e.g.,

agriculture, cutting, overgrazing, urban expansion, etc (Photo 1). Thirgood (1981) discussed that the spread of agricultural practices and animal grazing, the need of wood for shipbuilding, constructions and heating, the devastation by wars, all reduced the extent of the forest cover, resulting in progressively open and degraded woods, and, thus, bare land with eroded slopes, especially in mountain areas. Herbivores might indirectly affect the spatial pattern of the forests (Seifan and Kadmon, 2006). Spatial structure of natural vegetations is also affected directly by grazing or through modifying spatial structure of palatable species (Huntly, 1991).



Photo 1. Oak forest cutting for firewood in Lebanon (photo shot on April 29, 2005 at Kefraya north Lebanon "coordinates: $x = 35.722988$; $y = 34.2954694$; $z = 226$ m").

Natural causes are also highly active in disturbing forest ecology, in the Mediterranean region, mainly the climate change and fire and other natural hazards. Mediterranean forests became coppices-like form because of long history of human interference especially the cutting processes (Crowther and Evans, 1986). Mediterranean forests are highly sensitive to climatic changes (Peñuelas *et al.*, 2004). For example, some climatic models show an important decrease in water availability in semi-arid areas

of the Mediterranean, thus causing dramatic changes of the natural ecosystems (Jones *et al.*, 1996; Vicente-Serrano *et al.*, 2006).

These changes occur with different magnitude in the diverse area of the Mediterranean Basin. Eastern Mediterranean forests are facing drastic phenomenon of desertification where recent bioclimatic and biological trends indicate such phenomenon (MoA, 2003). While, southern Mediterranean has already faced changes from sub-humid to semiarid bioclimatic level (Barbero and Quézel, 1995). Due to high human intervention and many other factors, e.g., most Mediterranean forests can be considered as patches in different stages of development (Kruger *et al.*, 1983). These forests are unique in nature and possess extensive problems with regard to other region of the world.

In the old days studies at the Mediterranean forests were limited to plant collectors and then to botanists (Figure 2). After a physiognomic phase, phyto-geographers have investigated the Mediterranean forests where they deeply searched into the particularity of the area (Di Castri, 1981; Ozenda, 2002). The bioclimatic zones brought to the hands of the phytosociologists and the vegetation associations were described. At the Mediterranean landscape, spatial analysis is in its infancy and in various places remains missing, such as Lebanon.

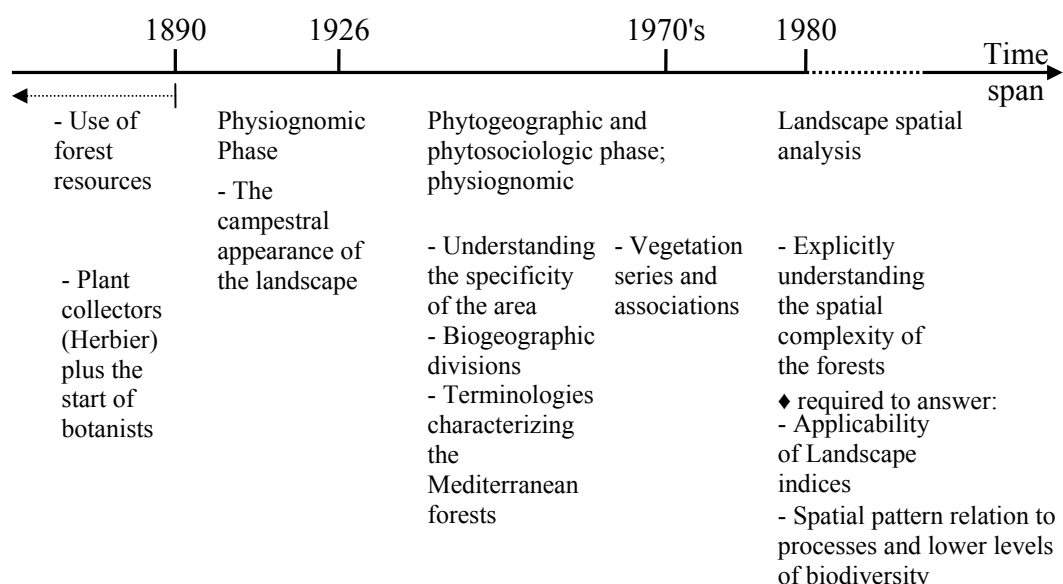


Figure 2. Evolution of studies at the Mediterranean forests (prepared in this manuscript).

Although landscape changes in the Mediterranean basin have been recently studied, yet most of those studies focused on quantifying the rate of land abandonment (García *et al.*, 2005), forest expansion or fire effects (Moreira *et al.*, 2007). One of the research priorities suggested for Mediterranean forests is “to study structural and functional interactions between landcover management and biological diversity at the level of forest stands and of the landuse mosaic” (Scaracia-Magnozza *et al.*, 2000). Since natural and anthropogenic factors play major role in shaping the ecology of Mediterranean forests, better knowledge is needed about the landscape spatial behavior of the forests.

Biodiversity in Mediterranean forests has not only spatial character, but also a temporal one. There are convergences and divergences among different Mediterranean regions with regard to biodiversity because of palaeogeographical (Verlaque *et al.*, 1997) and historical factors as well as ecological conditions (Quézel, 1985). Mosaic landscapes are common, where different patches of vegetations are found interleaved on various soils, topography, exposure to wind and sun, and fire history. For example, Beirut-Damascus (40 km) trajectory holds similar or higher number of species compared with the trajectory of Paris-Marseille (Mouterde, 1966).

2. Forest fragmentation

Fragmentation is an intuitive concept where it involves dividing something into a number of smaller pieces. Generally, the number, size and spatial distribution of the resulting pieces characterize fragmentation. A plate that is broken into 100 pieces is more fragmented than if same plate were broken into 10 pieces. Similarly, a plate broken into 10 pieces of equal size is more fragmented than a plate broken into 10 pieces, one of which is 90% of the original plate.

Forman (1997) defined the process of fragmentation as “the breaking up of a habitat, ecosystem, or landuse type into smaller parcels”. Fragmentation is a term used for the reduction or elimination of patches or connections between patches in a landscape (Kotliar and Wiens, 1990). Habitat fragmentation, ecosystem fragmentation and forest fragmentation are different terminologies used in ecological sciences. The separation of

these three terms requires further ecological understanding and clearly accurate definitions in ecology. Habitat fragmentation and forest fragmentation are sometimes confused with each other. Therefore, fragmentation has become a generic concept in ecology and its utility is under questioning (Bunnell, 1990). The term fragmentation has not been used consistently. Some studies include habitat loss as part of fragmentation; others consider it as a separate change. For example, habitat amount (total area) within a landscape might remain constant but the extent of habitat fragmentation changes; or both increase simultaneously (Figure 3).

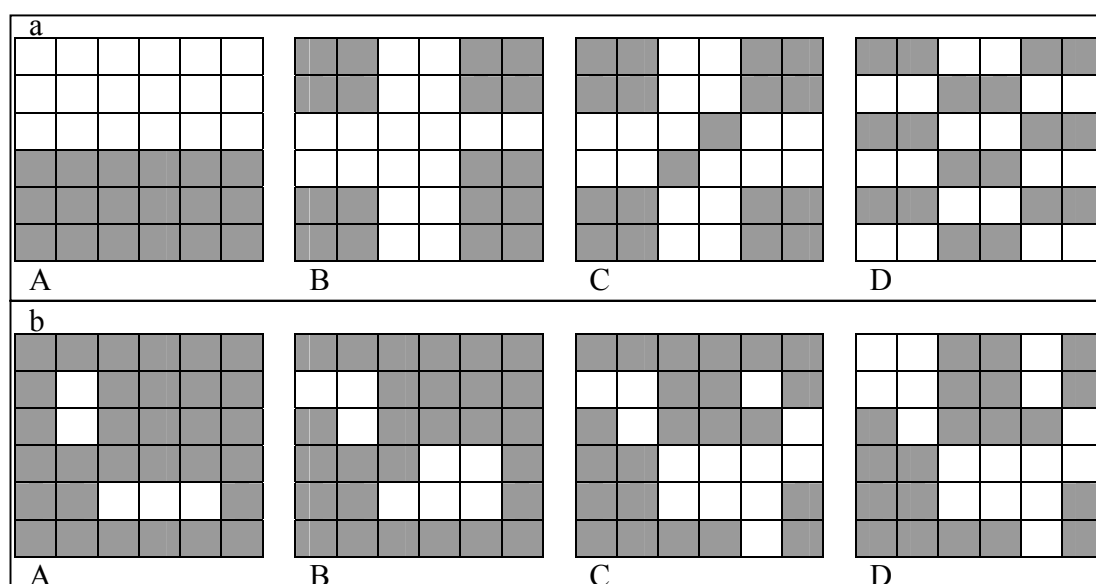


Figure 3: a) Four landscapes with same amount of habitat (in area) but with varying levels of fragmentations, when measuring patch size and edge length. Average patch size declines from (A) to (D), while edge length increase. b) As habitat availability declines, the component of fragmentation changes from perforation in (A) to isolated fragments in (D); habitat patch size decreases, edge length increases, and habitat patch isolation increases.

An organism (or community) will survive until loss of habitat reaches a specific threshold. This threshold depends on the region and the environment of the study. Habitat fragmentation increases the chance for a species (organism or community) to reach the threshold of mortality when loss of habitat occurs. However, the concept of threshold is

questionable (Lindenmayer *et al.*, 2005). Consequently, studies started to separate habitat loss from habitat fragmentation (Fahrig, 2001).

Habitats are areas that provide the resource requirements for discrete phase of a plant or animal's life (Southwood, 1981; Pacha and Petit, 2008). Habitat-area, on the other hand, is the amount of habitat within a landscape that meets the requirements of particular species. Habitat fragmentation could be defined as the emergence of discontinuity in an organism's (or number of organisms, or community) preferred environment (habitat).

Ecosystem fragmentation is the breaking of an ecosystem. For example, floodplain ecosystems are fragmented by eliminating the hydrological connectivity between different parts of the ecosystem (Thoms *et al.*, 2005). Ecosystem mainly used to mean forest woods or other natural patches (Gibson *et al.*, 1988; Geneletti, 2004). The term ecosystem is ambiguous in ecology; therefore, we preferred the terms forest loss and fragmentation.

Forest fragmentation is a form of habitat fragmentation, occurring when forests are cut down in a manner that leaves relatively small, isolated patches of forest. The intervening matrix that separates the remaining woodland patches can be natural open areas, farmland, or developed areas. Following the principles of island biogeography, remnant woodlands act like islands of forest in a sea of pastures, fields, subdivisions, urban settlements, etc.

The formation of heterogeneous mixture of small forest patches is an intermediate step in continuing fragmentation (Reed *et al.*, 1996). In severe ecological conditions, fragmentation progresses in various degrees; initially a patchy forest is transformed into fragmented one then to a number of forest fragments and finally to a singular insular tract or forest patch.

Forest fragmentation is a symptom that describes the illness (disorder) of a landscape. As forest fragmentation expands over a landscape, landscape biodiversity and integrity (biodiversity within the landscape) are threatened.

For simplicity and to facilitate the utilisation of terms, we use in this research forest fragmentation as the breaking of a forest patch into several discontinuous patches. We also use the term forest loss to describe area diminishing of one or several forest patches.

2.1. Causes of fragmentation

Fragmentation might be the result of either natural disturbances such as spontaneous fire (e.g. forest fragmentation increase fire risk and vice versa, e.g., Eriksson *et al.*, 2003), diseases epidemics (insect outbreaks, fungus, etc), drought, mass movements, landslides, storms, climate change (Iverson *et al.*, 1999) etc or artificial interference (anthropogenic disturbances) through clearing for agriculture (Santos *et al.*, 2002) and urban encroachment, socioeconomic and policies (drivers of forest fragmentation see Alig *et al.*, 2005), road construction, logging, clearcuts, grazing, introduction of alien/exotic species etc.

Pahari and Murai (1999) demonstrated the presence of high correlation between human population density and cumulative forest loss for a region. Changes in forest fragmentation correlate to the surrounding human landuse (Abdullah and Nakagoshi, 2007). For example, the fragmentation of the green belt around Moscow was the result of urban expansion (Boentje and Blinnikov, 2007).

Forest fragmentation is a phenomenon that threatens biodiversity worldwide. Lebanon is among the places where forests are subjected to severe fragmentation processes of natural or anthropogenic causes. Hence, extensive clearing for human settlements and agriculture has been carried out throughout history (Thirgood, 1981). In addition, population growth, urbanization, economic developments and conflict are among the external factors that significantly affect forests. Additionally, fire, overgrazing and over-cutting of wood products have contributed to forest degradation (MoE, 2001). For example, junipers and oaks are preferentially felled for charcoal production. Overgrazing is mainly in these two forest types at the presteppic environment where biodiversity is fragile. The stone pine (*Pinus pinea*) is mainly threatened by urban development and forest fires (Table 1). Pests and diseases also threaten the forests in Lebanon (MoE/LEDO, 2001). Forest holding stands of *Ceratonia siliqua* L. is described as highly fragmented (Talhouk *et al.*, 2005).

Table 1. Threats to forest types in Lebanon based on degree of severity (listed in MoE, 2001).

| Forest type | Abusive felling | Overgrazing | Urban expansion | Fires |
|--|-----------------|-------------|-----------------|-------|
| Kermes Oak* (<i>Quercus calliprinos</i>) | 3** | 4 | 3 | 3 |
| Haired Oak (<i>Q. cerris</i>) | 4 | 4 | 4 | - |
| Aleppo pine (<i>Pinus halipensis</i>) | 3 | 3 | 4 | 5 |
| Callebrian pine (<i>P. brutia</i>) | 3 | 3 | 3 | 5 |
| Stone pine (<i>P. pinea</i>) | 1 | 2 | 4 | 3 |
| Cedar of Lebanon (<i>Cedrus libani</i>) | 2 | 2 | 1 | - |
| Fir (<i>Abies cilicica</i>) | 3 | 4 | 3 | - |
| Junipers (<i>Juniperus excelsa</i>) | 4 | 5 | 2 | - |
| Cypress (<i>Cupressus sempervirens</i>) | 3 | 4 | 2 | 2 |

* *Quercus infectoria* could be found as mixed forest with *Q. calliprinos*. **Numbers are used as a scale of occurrence; low value means lower occurrence.

Another major cause of forest fragmentation in Lebanon is roads and other linear features, which require to be investigated thoroughly as it is the major threat to biodiversity.

2.2. Avoided and ignored fragmentation analysis

Landuse is rapidly changing forced by the socioeconomical variations. This has resulted in continuous transformations of the landscape. While depopulation and abandonment of agriculture is happening in one place, other areas are facing overexploitation of lands. Understanding the changes of the spatial distribution of vegetation cover is very important in such areas. This may help conduct better management models that human-nature relation can be sustained.

Man has constructed large road networks in order to maximize energy and benefit through using the landscapes with minimum labor investment. Roads and other passage types are among the major disturbances that cause important forest spatial changes. For example, roads disturb the diversity of birds within forests even if composition and structure might appear similar (Forman and Deblinger, 2000; Saunders *et al.*, 2002). Therefore, within patch disturbance might minimally affect composition, spatial characteristics and structure but it highly disturbs special processes and life forms. Linear object and features are rarely added in a spatial landscape analysis study because of the

low spatial resolution of the data source. For example, the frequently used data source, Landsat images, roads within forest patches are not detected.

Roads dissect vegetation patches, create edge effects, increase the uniformity of patch shape and size, and serve as barriers to species with limited mobility, invasion routes for weedy exotics, and direct sources of mortality to other species.

Clearcuts and roads alter the structure and function of forests by reducing forest cover, increasing edge density and isolate trees (Reed *et al.*, 1996). They also decrease core area and fundamentally change the size and shape of the patches (Tinker *et al.*, 1998). The number of forest patches increase followed by decreasing its size when linear features are added to fragmentation analysis (Geneletti, 2004).

Riitters *et al.* (2004) found that an assessment of fragmentation without incorporating road maps is potentially incomplete. On the other hand, incorporating only roads in fragmentation studies potentially ignores the effect of other linear features such as streams, grazing crossing roads and power transmission corridors.

Hemeroby or hemerobiotic state is an integral measure for the anthropogenic influence on landscapes or habitats. Jalas (1955) introduced this term in ecology to classify plant species according to the degree of the share in neophytic species. Hemeroby was then defined as “an integrative measure for the impacts of all human intervention on ecosystems, whether they are intended or not. The degree of hemeroby is the result of the impact on a particular area and the organisms which inhabit it” (Sukopp, 1976 in Fu *et al.*, 2006). Hemeroby of a forest patch is negatively altered with increasing human influence (Steinhardt *et al.*, 1999). The degree of hemeroby is measured by indicators such as the share of neophytic and therophytic species, morphological and chemical soil features and landuse types. Hemerobiotic measurements were used in the field of ecology in Central Europe and in China (Zechmeister and Moster, 2001; Fu *et al.*, 2006). Landuse intensity and landscape pattern changes can be attributed by the hemerobiotic state. As a measure for naturalness or conversely the human influence on ecosystem, hemeroby can be used for the assessment of ecological sustainability. The deviation of landscape compared to average situation is the hemerobiotic degree of that landscape (Peterseil *et al.*, 2004).

We will use hemerobiotic state of a forest patch to measure the degree of human interference in changing sustainability. Roads and linear features within a forest patch are major changes that we considered that they change the hemeroby of forests.

2.3. Consequences of fragmentation

Many studies demonstrated that landscape biodiversity and ecological conditions are negatively influenced by fragmentation of landscape patterns (Paton, 1994; Beir and Noss, 1998; Mazerolle and Villard, 1999; Hill and Curran, 2005). Fragmentation could lead to (i) accelerate local and global extinction of plants and animals (Farina, 1998); (ii) reducing species number; (iii) the interference in dispersal and migration processes; (iv) alter ecosystem inputs and outputs; (v) the exposure of isolated core habitats of the forests; (vi) interrupt nutrients, plants and animals flow between landscape ecosystems (Lovejoy, *et al.*, 1986; Baranga, 2004); (vii) changes in landscape spatial pattern configuration.

Fragmentation actually modifies biodiversity through four main mechanisms (Noss and Csuti, 1994):

1. *Initial exclusion*: when the fragments still hold most of the initial forest species.
2. *Isolation*: when the landscape becomes mostly inhospitable for native taxa.
3. *Island-area-effect* is when the smaller fragment has rapid extinction phenomenon of biodiversity.
4. *Edge effect*: when the core area of the forest reduced and the edge permits the entrance of invaders.

Consequently, fragmentation affects ecosystems by altering both abiotic and biotic factors. The flow of resources (organisms, nutrients, etc) changes between and within fragmented patches because it depends on the size, number, shape and configuration (monitored through techniques of remote sensing) of patches within landscapes (Figure 4). As an example, light, moisture, wind, soil regimes, etc changes under fragmentation processes (Saunders *et al.*, 2002). Patch edges receive more temperature and solar radiation and have different moisture conditions than patch core. Abiotic factors also changes and affected by biotic disturbances and vice versa.

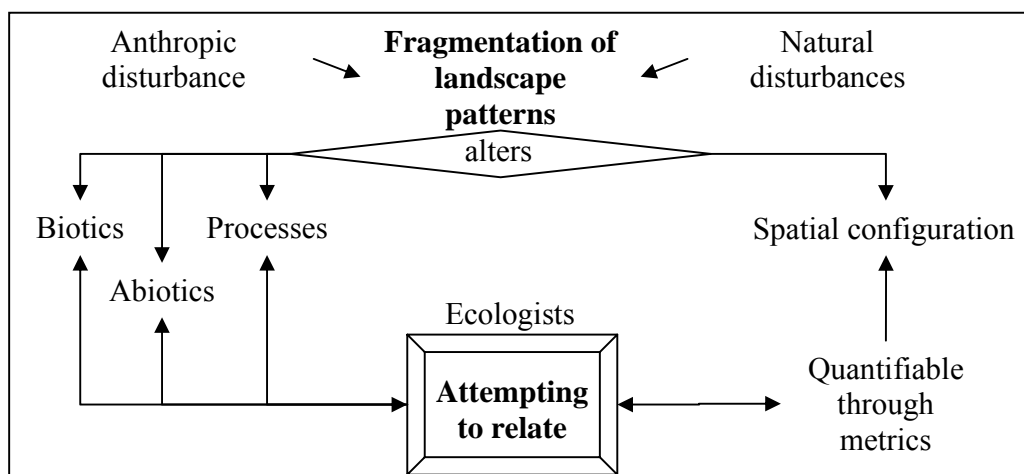


Figure 4. Attempts to discover fragmentation consequences (prepared in this manuscript as a conceptual view of the landscape fragmentation problem).

Although the degree of forest fragmentation (as well as connectedness) is used as an indicator for the status of biodiversity, fragmentation processes effect and consequences are very complex and interconnected; field evidence and measurements remain highly required (Bissonette, 2003). Haila (2002) explains, “The effects of fragmentation vary across organism, habitat types, and geographic regions”. As an example, large fragments might not guarantee higher species richness (Rudis, 1995).

Forman *et al.*, (1976) have found relationship between patch size and avifauna diversity. They spoke about a threshold allowing for the presence or absence of a species. They also pointed out that species are negatively affected by fragmentation especially at the patch edge. Other studies found that some native species require large area or have limited vagility that they will be affected easily by others able to disperse well in limited resources, such as in isolated patches (Dale *et al.*, 1994). Forest fragmentation has also altered plant animal interaction such as the trophic level of herbivory insects (Simonettia *et al.*, 2007). Nevertheless, forest fragmentation causes climate change (Laurance *et al.*, 1998), and negatively affects the regeneration of juniper forests (Santos and Tellería, 1994).

The consequences of fragmentation, however, are in its childhood phase of knowledge for ecologists. More studies are required to record detailed changes on

processes under different fragmentation circumstances and at different climatic conditions.

In Lebanon, the majority of the forest patches are facing fragmentation processes but this threat has not been yet investigated. For example, roads cross the forest patches freely and other human interference are even worse.

2.4. Mediterranean forest recovery

As known, vegetations around the Mediterranean region are mainly fragmented and are the result of under centuries of continuing stress. Vegetation recovery remains possible when, e.g., abandonment of agricultural areas and cessation of extensive grazing happen.

Regrowth forests are associated to shifting practice in short term period forest to cultivations then to land abandonment and natural regeneration of forests (Lugo and Helmer, 2004). However, regrowth forests might never assemble similar composition in flora and fauna to the pre-clearing situation of mature forest (Foster *et al.*, 1998), especially in arid areas (Pueyo and Alados, 2007). The regeneration pathways of regrowth are strongly dependant on landuse history such as the type and duration (Bowen *et al.*, 2007), as well as on climatic and even microclimatic conditions. In addition, forest regeneration depends on the severity of previous pests and diseases attack (Olivia and Colinas, 2007). Mediterranean forests have the potential to fast recover up to 80% post fire events in only three years period (Wittenberg *et al.*, 2007), depending on the forest type. Broadleaved forests recovered after forest fire by 2 years whereas coniferous has died in an experimental site in Portugal (Catry *et al.*, 2006). For example, grazing and cultivation had negative effect on regeneration of Holm Oak in Spain (Plieninger, 2007). However, oak forests in Lebanon face cutting events every 15 to 25 years for charcoal production; and though relatively rapid regrowth (sprouting) from mother tree occurs.

3. Forests and vegetations in Lebanon

3.1 Previous studies

Edmond Boissier was among the first botanist who studied the flora in Lebanon as part of the regional investigations between 1867 and 1884. Another survey of the flora was ready in 1896 by Post E. George under the name of “Flora of Syria, Palestine and Sinai from Taurus to Ras Mohammad”. The floral listing and investigations continued throughout the twentieth century as Louis Bouloumoy in 1930 wrote “flore du Liban et de la Syrie”. Between 1936 and 1940, Joseph-Marie Thiébaud published the “Flore Libano-Syrienne”. The 33 years work of Mouterde that was started in 1930, it was published in 1966 as Tome 1 “Nouvelle Flore du Liban et de la Syrie” (Mouterde, 1966), in 1970 as Tome 2 and in 1983 as Tome 3. Mouterde has constructed a valuable species list database and he corrected a number of previously misclassified plants. He also included the location and description of the sites that were investigated. He prepared drawings or “schema” for each plant in three volumes that are jointly used with the book. Other studies are worth mentioning that examined other individuals of the flora. In 1947, Mouterde had listed the arborescent species in the Levant. Whereas, Zohary (1961) had examined the differentiation of the oak species in the Middle East. The wild flowers was intensely investigated in the “Fleurs sauvage du Liban” (Nehmé, 1977) and in the “A thousand and one flowers of Lebanon” (Tohmé and Tohmé, 2002).

Mouterde (1947) provided some ecological information about the trees and shrubs associated with cedars in the Levant and this was the start for phytosociological studies. Basbous and de Tarade (1955) investigated the autecology of *Cidrus Libani*. Pabot (1959), Chouchani (1972) and Abi Saleh (1978) performed important phytogeographical, phytosociological and ecological studies. Pabot (1959) elucidated the various vegetation zones using the climatic characteristics and altitude and he listed the various vegetation types distinguishing each of the zones. However, Mouterde (1966) used quite different vegetation zones, finding that two of them were mistakenly used by Pabot precisely the subalpine and alpine zones.

Abi Saleh (1978) continued the work by describing and drawing limits to the vegetation zones and building an important phytosociological study in the country. Beals, (1965) provides some autecology information and communities of plants found at the cedars forests. The phytosociological studies as well as the vegetation-edaphic factors relationship were also investigated (Abi Saleh, 1976; Abi Saleh 1978; Abi Saleh and Safi 1998). Rey (1955) gave the distribution of cedar, in Lebanon, with relation to annual precipitation rate. Giordano (1956) investigated the total patch area of each forest type as well their distribution along the different altitudes. Chouchani *et al.*, (1974) gave some interpretations of the various forest associations of Lebanon.

Because of forest changes with time, floral investigation at the species level for the same locations has to be renewed and updated information becomes necessary. Many changes occurred since then; especially to the sites where samples were collected (Tohmé and Tohmé, 2001). Plants that were observed only in Syria are now found in Lebanon. Others were demonstrated to be distributed in different places that were noticed by Mousterde and many are disappearing (Tohmé and Tohmé, 2001). New species of wild flowers are discovered. Moreover, several species of almond trees disappeared and big menace was found at both natural and cultivated ecosystems when compared to previously listed species (Mousterde, 1966).

Consciousness to the severity of floral and biodiversity degradation, Lebanon has signed the Convention on Biological Diversity (CBD) in 1992 and ratified it in 1994. Since that date, the government is committed in Article 6 of the CBD to identify, conserve and sustain biodiversity. In an attempt to pave the road for further biodiversity studies, the government of Lebanon compiled the previous knowledge and studies concerning biodiversity in nine volumes taking into account various ecosystems, i.e., aquatic and terrestrial (Khouzami *et al.*, 1996). As part of this project, Abi Saleh *et al.*, (1996), compiled the previous floral investigations and listed 3761 terrestrial species. Other studies described the forests in Lebanon for the sake of conservation (Abi Saleh and Safi, 1995).

Mapping the natural vegetation started choosing one type of forest trees and then continued to overcome the various landcover classes each for different purposes. In this respect, Pabot (1959) has mapped the cedar patches of Lebanon and listed the associated

plants. El Hussein and Baltaxe (1965) constructed the first map of the country on 1/50,000 spatial scale.

Baltaxe (1966) listed the main woody species found in each forest-patch around Lebanon on 1/200,000 scale forest map. Zohary (1973), as part of a Middle East study, describes the geographical and the geobotanical distribution of the vegetation of Lebanon but no map was produced.

The ecosystem and vegetation map completed in 1988 (Abi Saleh and Safi, 1998) is the most important ecosystem phytosociological study from the past that considers whole Lebanon. Other landcover map encompasses very broad classes, e.g., broadleaf forest, coniferous forest, etc (FAO, 1990). A more detailed landcover map with extensive legend was established in 2002 (MoA/FAO, 2002). The delineated forest ecosystem in this landcover map “MOS (Mode d’Occupation du Sol)” show the prevailing tree species within the forest patch. Forest map of 2005 was made available after extensive field investigation but the map hold the same forest patch delineation of the landcover map of 2002 (MoA and FAO, 2005b).

3.2. Forest geography in Lebanon

Forests in Lebanon could be divided between broadleaved and conifers as to the Mediterranean. The broadleaved forests constitute the highest surface of the entire forest area in the country (Figure 5).

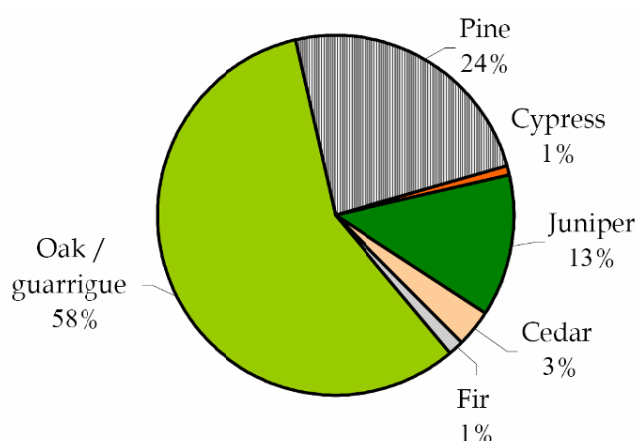


Figure 5. Percent distribution of forest types in Lebanon (Abi Saleh *et al.*, 1996).

Forest types of Lebanon were classified under seven different homogenous patches (Figure 6). They are forests of:

- (1) *Quercus calliprinos* Webb.,
- (2) *Pinus pinea* L.,
- (3) *Pinus brutia* Ten.,
- (4) *Cedrus libani* A. Rich.,
- (5) *Juniperus excelsa* M.B.,
- (6) *Abies cilicica* Ant. & Ky, and
- (7) *Cupressus sempervirens* L. (El Hussein and Baltaxe, 1965).

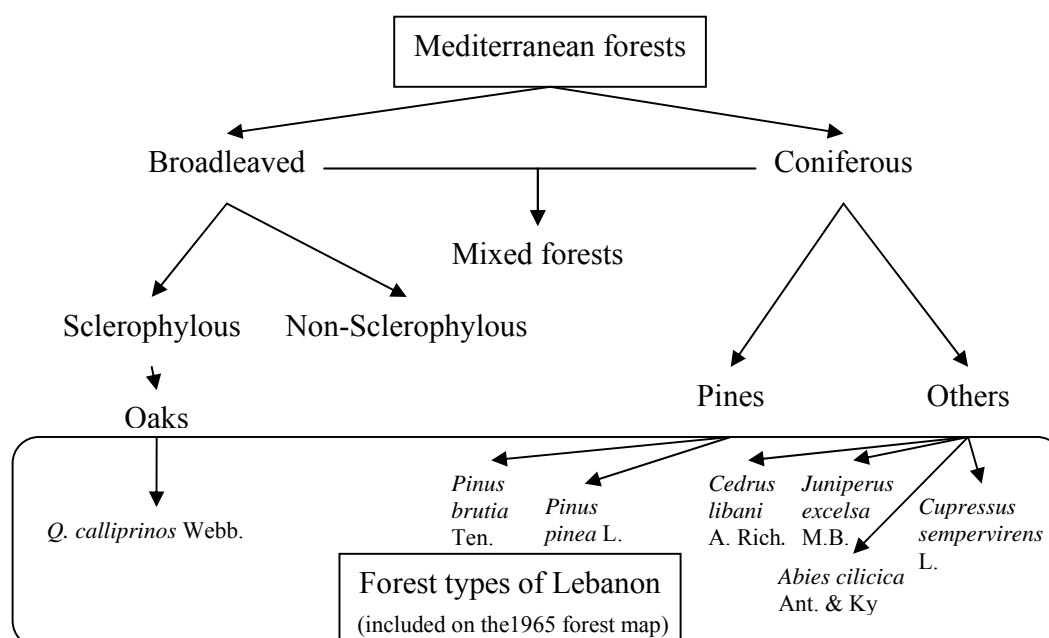


Figure 6. Forest types of Lebanon following the 1965 forest map; relation to Mediterranean forests (prepared in this manuscript).

The landcover map of Lebanon was produced in 2002 but it is based on satellite images of 1998. Forest types of Lebanon were generalized into six homogenous patches: (1) *Pinus* spp., (2) *Cedrus* spp., (3) *Abies* spp. (4) *Quercus* spp., (5) *Juniperus* spp. and (6) *Cupressus* spp. (MOA/MoE, 2002) Pines were joined under one forest type (forest class) if compared to previous forest map of 1965. The forest map of 2005 has more

generalized the forests between: (1) *Pinus pinea* L., (2) *other pines*, (3) *Cedrus libani* A. Rich., (4) *Juniperus excelsa* M.B. (5) *Abies cilicica* (Ant. & Ky), (6) *Cupressus sempervirens* L., (7) mixed coniferous forests, (8) broadleaved evergreen forests, (9) broadleaved deciduous forests, (10) mixed broad leaved forests, (11) mixed coniferous and broadleaved forests, and (12) riparian forests (MoA and FAO, 2005b).

Conversely, field data reveals another forest type that should be added onto the maps. For example, forest maps list *Quercus calliprinos* Webb. on places dominated by *Ceratonia siliqua* L (Kharroub). This tree (Kharroub) is distributed and generally found dominating forest patches of 0-500 m above sea level. Therefore, forest patches shown on previous maps must be named according to this tree (Kharroub) and not always under oaks (*Quercus calliprinos* Webb.). Several studies, mainly field data and observations, have found Kharroub to dominate forests of thermo-Mediterranean bioclimatic zone (0-500 m) (Chouchani, 1972; Abi Saleh, 1978; Talhouk *et al.*, 2005). Nevertheless, field studies also prove that higher elevation forest patches of oaks (*Quercus* spp.) are dominated by *Quercus infectoria* Olivier ssp. (Abi Saleh, 1978; Abi Saleh *et al.*, 1996). This is also another fact that has to be searched and included onto the forest maps.

Consequently, landscape biodiversity (composition of a landscape) should not only show seven forest patch types. Two other forest types must be included which they are the *Ceratonia siliqua* and *Quercus infectoria*. Compositionally, landscapes in Lebanon holds nine different forest types.

3.3. Forests abiotics relation

The distribution of forests in Lebanon is highly influenced by altitude, though it is climatically related. Lebanon was divided into ten bioclimatic zones under Mediterranean and Mediterranean presteppe climates (Table 2 and 3). As an example, *Ceratonia siliqua* habitat is within the thermo-Mediterranean bioclimatic zone, while *Quercus calliprinos* has wider range of climatic behavior.

Table 2. The distribution of forest types according to the different vegetation zones.

| Floristic ensemble | Forest types | <i>Q. calliprinos</i> * | <i>Ceratonia siliqua</i> | <i>Pinus pinea</i> | <i>Pinus brutia</i> | <i>Cedrus libani</i> | <i>Juniperus excelsa</i> | <i>Abies cilicica</i> | <i>Cupressus sempervirens</i> |
|-------------------------|--------------------------------|-------------------------|--------------------------|--------------------|---------------------|----------------------|--------------------------|-----------------------|-------------------------------|
| Mediterranean | Thermo (0-500 m a.s.l) | | | | | | | | |
| | Eu (500-1000 m) | | | | | | | | |
| | Supra (1000-1500 m) | | | | | | | | |
| | Mountainous (1500-2000 m) | | | | | | | | |
| | Oro (>2000 m) | | | | | | | | |
| | Medit. presteppe (1000-1500 m) | | | | | | | | |
| Mediterranean presteppe | Supra (1500-2000) | | | | | | | | |
| | Mountainous (2000-2500 m) | | | | | | | | |
| | Oro (>2500 m) | | | | | | | | |
| | | | | | | | | | |

**Quercus infectoria* could be found more dominant in oak forests at Supra and mountainous at both floristic ensembles.

Although forest types are identical from some bioclimatic zones, their phytosociology perfectly differs (Abi Saleh, 1978). *Quercus Calliprinos* of thermo-Mediterranean, for example, has different vegetation associations with regard to presteppic environment.

Table 3. Vegetation zones in Lebanon and their forest types with respect to different Lithologies (modified from Abi Saleh 1978).

| Altitudinal vegetation levels | | Phytosociological series in each vegetation zone of:* | | | | | | | | | | | | | |
|---------------------------------------|--------------------------------------|---|-------|-----|----------|----------|--------|-----|--------|-----|-----|-----|-----|-----|-----|
| | | Altitude (m) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| Mediterranean (from sea) ^u | Thermo-Mediterranean | 0-500 | Lst** | Lst | - | - | ma-Lst | Sst | ma-Lst | - | - | - | - | - | - |
| | Eu-Mediterranean | 500-1000 | - | Lst | Lst | - | ma-Lst | Sst | ma-Lst | - | - | - | - | - | - |
| | Supra-Mediterranean | 1000-1500 | - | Lst | Lst, Sst | Lst, Sst | - | Sst | - | - | - | - | - | - | - |
| | Mountainous-Mediterranean | 1500-2000 | - | - | - | - | - | - | - | Lst | Lst | Lst | Lst | Lst | Lst |
| | Oro-Mediterranean | >2000 | - | - | - | - | - | - | - | - | - | - | Lst | - | - |
| Med. presteppic (inland) ^d | Oro-Mediterranean | >2400 | - | - | - | - | - | - | - | - | - | - | Lst | - | - |
| | Presteppic | | | | | | | | | | | | | | |
| | Mountainous-Mediterranean presteppic | 1800-2400 | | | | - | - | - | - | - | - | - | Lst | - | - |
| | Supra-Mediterranean presteppic | 1400-1800 | | Lst | Lst | - | - | - | - | - | - | - | - | - | - |
| | Presteppic-Mediterranean | 1000-1500 | - | Lst | - | - | - | - | - | - | - | - | - | - | - |

* 1. *Ceratonia siliqua* L. 2. *Quercus calliprinos* Webb. 3. *Quercus infectoria* Oliv. 4. *Quercus Cerris* L. 5. *Pinus brutia* T. 6. *Pinus pinea* L. 7. *Cupressus sempervirens* L. 8. *Cedrus Libani* A.Rich. 9. *Abies cilicica* Ant. 10. *Abies cilicica* Ky. 11. *Juniperus excelsa* M.Bieb. 12. *Quercus cedrorum* Ky 13. *Quercus brantii* Lindl. ssp. look. (Ky) ** Lst = on limestone; ma-Lst = on marly limestone; Sst = on sandstone; - = absent. u is from the sea line upward; d is from mountain peak and down slope.

3.4. Canopy closure

Canopy closure is the percentage of ground area shaded by overhead foliage (Daubenmire, 1959). The forest density or canopy closure plays important ecological role because it greatly affect animals and plants within the forest (Théry, 2001).

Forest canopy closure was shown in Lebanon on the forest map of 1965 and the landcover map of 2002. The forest map uses percentage-like degree of forest canopy closure while the landcover map uses only the term “dense” and “clear”.

The canopy closure of the forests is an important index in highly disturbed areas like the Mediterranean. The spatial coverage of a forest (total surface area) might undergo little or no change, while its canopy closure might change intensely. This will not affect landscape spatial pattern measurements, but the forest quality is changing. Therefore, canopy closure is an important measure that has to be investigated clearly and subjected to monitoring.

Chapter 2

2. Landscape spatial configuration analysis

1. Landscape: heart concept in ecology

1.1. Landscape

In 1849, Alexander von Humboldt glossed the term landscape as the "sum total of the characteristics of a region". A common meaning of the term landscape is being a spatial portion of land that is seen from a certain point. This would be what we see, i.e., physiognomy of the land that is embraced in a single glance or physiognomy of the region that we pass through or fly over (Noirfalise, 1988). Pitte (1983 in Burel and Baudry, 2003) listed this definition from Littré "A landscape is an extent of land that is seen in a single view. A landscape that has been seen in all its parts one after the other has not been really seen. It must be seen from a sufficiently high elevation, where all the objects dispersed around are brought within a single glance". Le Petit Larousse defined landscape as "étendue de terre qui s'offre à la vue".

Landscape is then a view of land so that the constituting elements organize in space. It is the image of spatial structure on local scale. This three dimensional view is therefore limited, considering the volumes, screen, different perspectives and viewing angle (Pinchemel, 1992). The landscape is situated on the hinge between the entity: *the place*, *space* and the subject: *observant*, between the reality and representation, between the nature and society (Berque, 1995).

Other than the spatial dimension, landscape has also a social one. Many have denounced, "The fallacious nature of the paradisiacal and harmonious image of rural landscape, in reality is not preserved" (e.g., Joliveau, 1994). Sociologists consider the landscape as a simple social construction based on special representation of different societies. Geographers, historians, ethnologists, and sociologists have recognized that the landscape results from relationships between nature and society (Weber, 1983; Chatelin

and Riou, 1986). Landscape is an area made up of a distinct association of forms, both physical and cultural (Sauer, 1963).

Hartshorne (1939) found the term confusing with duality and suggested its removal from geographical inquiry. The new division of science into many disciplines, however, removed the duality and complexity around the term, where landscape concepts each served the specific purposes within a specific discipline (Shaw and Oldfield, 2007).

1.2. Landscape ecological approach

Ninety years following von Humboldt, Troll introduced the term landscape ecology (Vink, 1983). He intended to combine ecological and geographical disciplines as an attempt to link spatial structures and ecological processes. Nowadays, landscape is an integral part of landscape ecological studies, where many definitions of the term have emerged. Ecologists went deeper than only using the visual aspect of the landscape. This fact is reflected in the following expressions and definitions:

- “A landscape may be conceived as a pattern of ecosystems related to one another along an environmental gradient” (Whittaker, 1967).
- “A landscape is a kilometer-wide area where a cluster of interacting stands or ecosystems is repeated in similar form” (Forman and Godron, 1981).
- “Landscape is a portion of heterogeneous territory composed of sets of interacting ecosystems that are repeated in a similar fashion in space” (Forman and Godron, 1986).
- A landscape is like a functional ecosystem at large scale (ecopaysage) (Froment, 1987).
- “Landscape is a level of organization of ecological systems that is higher than the ecosystem level. It is characterized essentially by its heterogeneity and its dynamics, partly governed by human activities. It exists independently of perception” (Burel and Baudry, 2003).

Consequently, landscape ecology considers the landscape as an ecological system, i.e., ensemble of physical, chemical, and biological elements where their interactions determine life conditions (Baudry, 1986). Landscape is a complex system, heterogeneous

and structured in a way that the different parties are in interaction. In other words, landscape is number of interrelated ecotypes and spatial repartition of living things.

Landscape has physical borders or limits where animal and plant populations interact. Landscapes might be separated by differentiation in climatic parameters (temperatures, precipitations, sunlight, wind, etc) and substratum characteristics (Soil types, water availability, nutrients, etc). The composition and configuration of these units in time and space (spatial and temporal) determine the vigor of interchanges between animal and plant populations within landscape.

1.3. Landscape spatial elements

Landscape is a continuously changing phenomenon (time dependent). However, a momentaneous perception of landscape must be available within the hand of ecologist to perform landscape analysis. Therefore, landscape is represented in a scene (view, image and photo). We, indeed, freeze the landscape at the glance where at this moment the landscape is the result of previous processes and functions related to prior landscape elements. Another glance of the landscape in the future will be considered as monitoring of processes and functions if compared to previous situation.

Landscapes are divided into manageable sub-systems that are being able to be dealt methodologically. The landscape is represented on an area of land, as common consensus between all disciplines. This land will have units that might be unmissed objects like forests, fields, roads, homes, etc, i.e., objects that are clearly seen. Ecologically, landscapes are built from the interactions between and within these spatial elements (corridors, patches and matrices).

Ecologists have used various terms referring to the basic elements of a landscape as follows: ecosystems, ecotopes, biotopes, landscape components, landscape elements, landscape units, landscape cells, geotopes, facies, habitats and sites, patches, etc. Any of the terms when used, it must be defined according to the preference of the researcher (Forman and Godron, 1986).

Considering that ecosystem is not yet completely defined in ecological literatures (Sarkar and Margules, 2002.), the following definition of landscape was adapted for the

rest of this research: *Landscape is an area of land composed of ensembles of spatial patterns resulted from processes and functions that belong to prior and up to the moment of depiction.*

Landscape ecology considers the landscape as being composed of three types of spatial units: patch, corridor and matrix. Landscape will have patches either isolated or connected by corridors, which demarcate landscape (Figure 7).

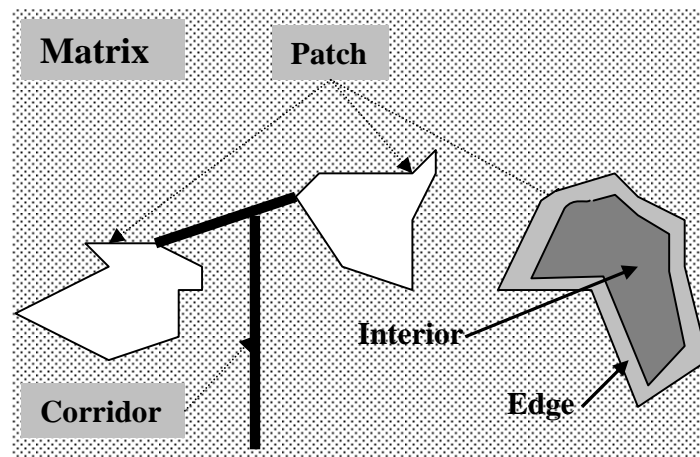


Figure 7. The three spatial components or elements of landscape (modified from Burel and Baudry, 2003).

a- Patch

Patch definitions all circles around the concept that it is the homogeneity in a discrete spatial boundary (Levin and Paine, 1974; Roughgarden, 1977; White and Pickett, 1985; Antolin and Addicott, 1991); patches have the following characteristics:

- Patches represent areas of relatively homogeneous environmental conditions at a particular scale. The patch boundaries are distinguished by abrupt discontinuities in ecotones or environmental character states from their surroundings of magnitudes that are relevant to ecological phenomenon under consideration (Kotliar and Weins, 1990).
- Patches is a relatively homogeneous nonlinear area that differs from its surroundings (Forman and Godron 1986).

In other words, patches are landscape components that could be easily encircled by an outline or boundaries within landscapes. They appear as isolated individuals in predominant space that is defined by one, e.g., landcover type. Defined by their vegetations, they are usually resembled as islands that could be isolated woods or water bodies in the middle of agricultural area (matrix concept). Patch can be described by its area, perimeter (edge), interior, type (or value) and neighbor(s) (Figure 7).

However, patches depend on spatial and temporal scales. A patch represented on a scale might have internal structure of number of patches at finer scale (Kotliar and Wiens, 1990). Therefore, regardless of a patch definition, mosaic of patches could be represented differently with changes in spatial scale. The studied organism or individual stops to respond to scale differences after a limit (Kolasa, 1989). There should be a limit between finest or coarser scale levels to perform the required analysis. The patch stays meaningful until the used scale does not refer to the object studied. Therefore, determination of an ecologically significant and representative scale is one of the initial steps in a landscape analysis (Meetenmeyer and Box, 1987).

The characteristics of the patch vary with the perception of the viewer. A single small watershed could be suitable for nutrient cycling but the entire region might be considered for certain bird investigations.

Consequently, the patch depends on the subject studied, i.e., a patch could be delimited according to the needs of the study. It is a geographically precise unit of measurement but it depends on scale. This research defines a patch as landcover class (group of spatially contiguous pixels of same category), such as a group of forest pixels.

b- Corridor

Corridors are defined as “narrow strips of land which could be found isolated but are usually attached to a patch of somewhat similar vegetation” (Forman and Godron, 1986). Three different types of corridors exist according to their dimensions as follows:

- *Line corridors* with very narrow width do not allow interior environmental conditions to develop.
- *Strip corridors* is little wider enough for interior conditions to develop.
- *Stream corridors* have special category.

Corridors could also be defined according to their function in the landscape into:

- “*habitat corridors*” provides connectivity between landscapes for natality and they might be consider as habitat by themselves;
- “*facilitated movement corridors*” also increase the connectivity of landscapes for the focal organism but necessary for reproduction; and
- “*barrier or filter corridors*” work as barriers or filters for the flow of energy, mineral nutrients, and/or species across landscapes.

Consequently, corridors are linear in nature, which differentiates them from patches. They are defined for their structure and/or function. Corridors could decrease connectivity for the focal process; or could be sources of abiotic and biotic effects on the surroundings through modifying the inputs of energy (e.g. mineral nutrients, species, etc.) and thereby functioning effect of the environs.

c- Matrix

Matrix is a term used in various disciplines, e.g., mathematics, geology, soil, ecology, medicine, biology, etc. It is a surrounding substance within which something else originates, develops, or is contained. Matrix is like a womb or a place where something is generated. A matrix is also the solid matter in which a fossil or crystal is embedded (<http://dictionary.reference.com>). While, Forman and Godron (1986) describe matrix as a homogeneous mass in which small-differentiated elements appear. For example, in soil science the matrix of fine material in which stones is embedded.

Insertion of the matrix notion into landscape ecology aims to characterize the landscape elements with regard to their importance. The matrix element within a landscape is the one that is characterized with the highest criterion. Forman and Godron (1986) used the following criteria for a matrix: (1) relative area, (2) connectivity, (3) control over dynamic, (4) and combination of the three previous criterion.

2. Fragmentation and landscape spatial analysis

In early 1980s, landscape ecology evolved from a descriptive discipline to an accepted quantitative and experimental science. Modern landscape ecologists study the

spatial variation in the structure, function and change of heterogeneous land areas that are composed of interacting ecosystems (Forman and Godron, 1986; Forman, 1997). ‘Structure’ refers to the spatially related features of elements and their spatial interrelationship within the landscape. In the last decade, landscape ecological studies elucidated the relation between landscape structure (i.e. patterns) and landscape functioning (i.e. processes) at different spatial scales (Forman, 1997; Risser, 1999). Consequently, the landscape has quantifiable spatial representation. The spatial representation of a landscape is called landscape spatial patterns (Figure 8).

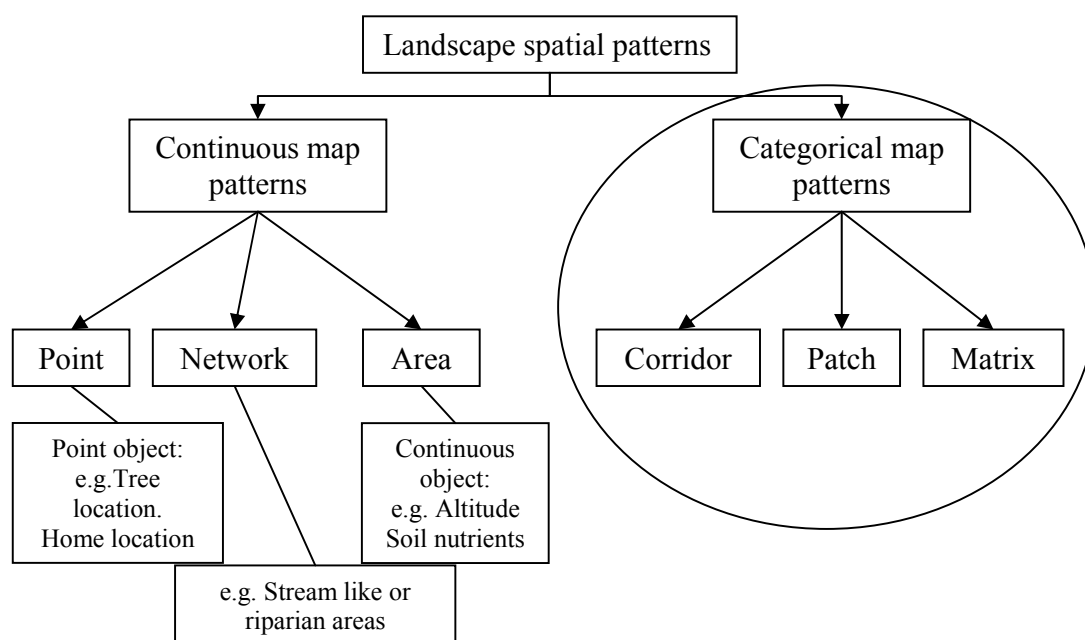


Figure 8. Spatial patterns of landscapes.

Patterns of a landscape depend on the patch definition used for the purpose of the study. Accordingly, the pattern might be continuous or categorical. As previously mentioned we deal with forest patches at the categorical representation of landscape.

Landscape structure is divided in two components “*composition*” (the amounts of various types of elements in the landscape) and “*configuration*” (the spatial arrangements of landscape elements) (Turner, 1996). Both, *composition* and *configuration* explain the landscape pattern (O’Neill *et al.*, 1988). *Composition* refers to the variety and relative abundance of patch types represented on the landscape. *Configuration* means the spatial

arrangement, position, orientation, or shape complexity of patches on the landscape. Configuration is quantified using landscape metrics.

2.1. Landscape metrics and their utilizations

The proportional area of patch types in a landscape (quantity) is the most commonly applied measure of landscape patterns (e.g. Kobler and Adamic, 2000). However, other landscape pattern characteristics such as patch isolation (Hanski, 1994), fragmentation and connectivity (e.g. Reunanen *et al.*, 2002) greatly affect landscape biodiversity and ecological processes. Literally hundreds of indices of landscape patterns were developed.

Landscape metrics were developed based on the theory of information theoretic measures (Shannon and Weaver, 1964) and the fractal geometry (Xia and Clarke, 1997). Landscape metrics are mathematical descriptors (Gustafson, 1998). Riitters *et al.*, (1997) and McGarical and Marks (1995) provided a useful mathematical summary of landscape metrics. Landscape metrics are tools that characterize the geometric and spatial properties of a patch or of a mosaic of patches in a landscape. While individual patch have few attributes, a landscape has variety of aggregated properties. Landscape indices or metrics could be defined at three levels:

- (i) *Patch-level metrics* are those defined for individual patches (area, perimeter, type and neighbor).
- (ii) *Class-level metrics* are integrated over all the patches of a given type (class).
- (iii) *Landscape-scale metrics* are further integrated over all patch types or classes over the extent of the data.

Landscape metrics could be used to quantify changes of landscape pattern when computed for different periods (Turner, 1996). Landscape metric research studies have been conducted at a number of different levels of sophistications. In forest fragmentation domain, studies have ranged from using metrics as simple landscape descriptors (e.g., Fuller, 2001), to empirical evaluation of the correlation between metrics (e.g., Tinker *et al.*, 1998), to the use of metrics as indicators of environmental risk (e.g., Wickham *et al.*, 2000).

2.2. Accuracy of forest fragmentation analysis

Landscape indices were developed to characterize landscape patterns based on representations of categorical map elements (O'Neill *et al.*, 1988). Spatial data representation (categorical maps) depends on data aggregation methods and zoning as recognized by quantitative geographers. It is the so-called *modifiable areal unit problem* - MAUP- or minimum mapping unit -MMU- (Openshaw and Taylor, 1981). Therefore, landscape indices are directly related to changes in spatial scale and chosen themes (organizational level of the study). Ecologists considered spatial scale a dichotomous term referring to *grain* (pixel size, smallest distinguishable area; synonymous with resolution, minimum mapping unit MMU) and *extent*-overall study area (Pascual-Hortal and Saura, 2007).

3. New data and conceptual problems

3.1. Remote sensing in landscape analysis

In recent years, the use of satellite imagery in ecological research has increased dramatically. The widespread availability of satellite images and of friendly image processing software have drawn ecologists to employ remote sensing to address environmental issues at landscape and regional levels. Common use of remotely sensed data is landcover map production (Boentje and Blinnikov, 2007), which the base of landscape analysis.

Remote sensing provides four broad types of information for environmental monitoring and management; these are landscape composition, landscape pattern, biophysical parameters, and their changes in time (Romero and Luque, 2006). Remote sensing also offers an inexpensive means of deriving complete spatial coverage of large areas in a consistent and in an updated manner (Muldavin *et al.*, 2001). Image repetition acquired for the same area (time series), synoptic coverage, and rapid availability of digital format with wide range of analytical methods are three important advantages for choosing remote sensing in landscape ecological evaluations. Remote sensing data is a valuable alternative to large and intensive fieldwork especially at inaccessible mountain areas and for a variety of purposes.

Depending on the study purpose (monitoring, analyzing, quantifying, time series, etc), ecologists could chose from large variety of sensors. Remote sensing offers sensors such as multispectral (TM, SPOT, AVHRR, etc), hyperspectral (CASI, AVIRIS-airborne, Hyperion, IRS, etc), and radar (SAR, LiDAR, etc), as well as high spatial resolution sensors (IKONOS, QuickBird, etc). For example, forest fragmentation studies have been conducted using data derived from the interpretation of aerial photographs (LaGro, 1991) and digital analysis of satellite imagery on regional or global scale (Matsushita *et al.*, 2006; Boentje and Blinnikov, 2007). Monitoring of changes and understanding its linkage to ecological processes might be achieved by a thorough detailed spatial knowledge of the landscape (Spence, 2001).

Remote sensing is advantageous in this type of studies, where decades of changes could be examined (Echeverria *et al.*, 2007). In addition, one of the realistic ways to acquire repeatable information at the scale of the landscape is through satellite remote sensing.

Using multiple image processing techniques, e.g. image classifier and segmentation, can be combined with field data to enhance capabilities of remote sensing (Franklin and Woodcock, 1997). Since satellite images became the basis of spatial information that required building the digital mosaic of a landscape and computing landscape indices, new advances in remote sensing increases the accuracy of analysis. Different image classification techniques have been tried to assess landscape spatial patterns. The new approach is the object-oriented classification that proved to be very useful for landscape assessment (Mathieu *et al.*, 2007). Multiple image processing techniques, e.g. image classifier and segmentation, is frequently used (Franklin and Woodcock, 1997).

3.2. Landscape spatial analysis inherited inaccuracy

Although ecologists started in late 1970s studying the effect of scale on landscape ecological studies (Openshaw and Taylor, 1979), the promise of remote sensing to solve landscape level research has usually accepted as high (Matsushita *et al.*, 2006). However, this is not always true (Meyer and Werth, 1990; Holmgren and Thuresson, 1998). One of the reasons of failures in remote sensing application is probably the poor understanding

by ecologists of the limits this technology holds and of the methods used to assess accuracy. Therefore, ecologists require considering overview on (1) feature description and spatial representation and (2) accuracy assessment (Fassnacht *et al.*, 2006).

The wide variety of remote sensing raw data encouraged studies to undertake the effect of spatial resolution on landscape indices (Benson and MacKenzie, 1995; Saura and Castro, 2007). Appropriate classification of remotely sensed data and choosing the workable spatial and spectral resolutions are criteria for having accurate landscape indices calculations. In other words, the scale and resolution chosen for a study affect the quantification of landscape fragmentation (Benson and MacKenzie, 1995). For example, in a fragmentation study the smallest patch size depends on the resolution and scale of the satellite image. High-resolution satellite images allow the detection of small sized patches that lead to increase in patch number (Turner *et al.*, 1989). Several studies have demonstrated information loss on a gradient from fine to coarse grain (Laymon and Reid, 1986; Cardillo *et al.*, 1999). Coarse grains result in loss of rare landscape types (Turner *et al.*, 1989). Landscape patterns appear as noise when grain is too fine and as constants when grain is too coarse. The responses of landscape metrics, however, to changing grain size might vary among landscapes and metrics.

Although many studies have provided insights into the effect of spatial resolution on landscape indices (Saura and Castro, 2007), it is not yet fully understood how fragmentation indices are affected by spatial resolution. The behavior of various landscape indicators at different scales is not clear. Landscape indices often do not change linearly with scale difference, but rather in a stepwise fashion until a threshold is reached (McShea *et al.*, 2005). The lack of studies that compare landscape indices across scales seriously limits the potential usefulness of quantitative analysis of landscape patterns.

Landscape indices have also other types of utilization problems (Figure 9); they might not correlate with processes that could be one of the main reasons behind computing these indices (Li and Wu, 2004). Landscape indices and their relation to processes still an important problem that faces ecologists. All these difficulties when using landscape indices are questioning the ecological significance of such indices. Dilemma of three axes is therefore drawn: conceptual use of the indices, complexity of results and improper use.

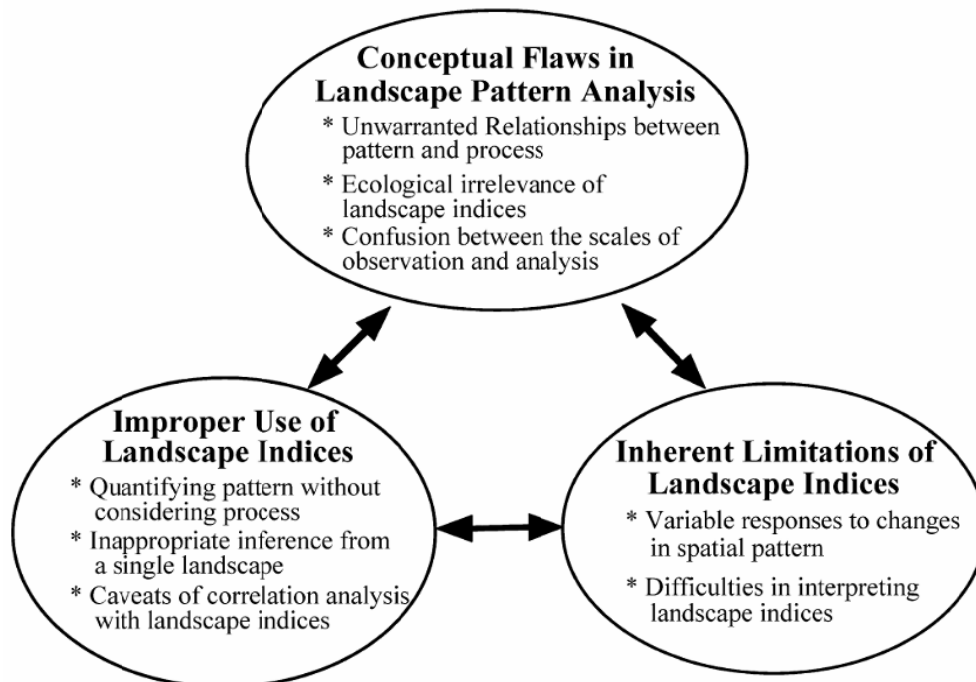


Figure 9. Three types of problems in landscape analysis with pattern metrics: conceptual flaws, improper uses, and inherent limitations of landscape indices. Each type manifests in several forms that overlap with the other types (Li and Wu, 2004).

These complications in landscape analysis are sometimes fatal to attempts that try to relate spatial pattern to ecological processes. The conceptual flaws are mainly the unwarranted process-pattern relationships, ecological insignificance of landscape indices, and confusion between observation and analysis scales. Two of the common inherent limitations of landscape indices are variable responses to certain changes in spatial pattern and difficulties in interpreting landscape indices. These limitations may lead to misuse of landscape indices when they are not properly treated. Examples of landscape indices misuse are: quantifying pattern without considering process, inappropriate results from a single landscape and failure to deal with caveats of correlation analysis with landscape indices. Given the necessity and importance of spatial pattern analysis, these issues must be addressed promptly.

Landscape ecology searches for any relationships between pattern and process that explain the status of the world and how it appears. Not all ecological processes affect

patterns and at the same time spatial patterns do not affect all processes. Landscape structure is measured through landscape indices. Ecologically relevant landscape index could link the structure to the dynamic of ecological processes. Moreover, the landscape spatial pattern must answer or reflect the characteristics of the system-studied and the question asked. The scale of observations should be converted into relevant data related to the investigated subject. Landscape indices might also remain unaffected if landscape changes in certain manner. Interpreting indices remains poorly understood, e.g., what the index really measures is uncertain even when the analytical aspects of most indices are quite clear.

On the other hand, landscape indices might be test or used in different manner and conceptual ways. The relation of processes to landscape indices could be tested through comparing data from the past with others from, e.g., real time. If processes is reflected through indices then computed indices on data from the past should answer changes occurred in the proceeding time.

Another use of landscape indices is how different landcover types are related geometrically to each other. Usually, landscape indices are used to investigate the structural configurations of one landcover nature (e.g. forests). Instead, landscape indices might be used to answer how one landcover type affects another. Changes in the structural configuration of two or more landcover types with regard to each other could provide better ecological concern.

Moreover, landscape indices require further testing on Mediterranean landscapes as used in other places. Although many landscapes are out to the reach of ecologists but an area like the Mediterranean might need other or new indices and different conceptual use.

3.3. Landscape change detection and diachronic analysis of different data sources

Diachronic and time series analyses, through cartographic and/or satellite data, seem to be an integral part of researches related to forest and life forms changes. Therefore, great numbers of methods were developed to obtain change information of landscapes (Jensen, 1996). Failure to understand the impact of sensor system and environmental characteristics will lead to inaccurate result in a change detection study. In diachronic

analysis (change detection or any other temporal analysis), data must be thoroughly investigated for their sources and their preparation methods must be greatly understood. The data needed for change investigation studies (diachronic times) might be gathered from variable sources such as field visits, cartographic (categorical maps) and remote sensing (satellite, aerial photos). These facts always depend on the availability of data. Homogenization of different data is an important step in any diachronic research analysis.

Diachronic analysis of a landscape has different nomenclature based on the type of the study, e.g., multitemporal change detection, time series analysis, multirate, etc. Change detection analysis (diachronic analysis), through satellite remote sensing, require special care when choosing different data. Accuracy of change detection study depends on issues related to image-related characteristics and to algorithms used. Image related characteristics are temporal resolution, spatial resolution (and look angle), spatial resolution, atmospheric conditions, and landcover conditions (soil, vegetation phenological cycle). The algorithms of change detection are post-classification comparison, write function memory insertion, image arithmetic, manual on-screen digitization of change, and image transformation. It is useful to identify these characteristics and their impact on change detection research results (see Table 4 for more details and methods). In other words, obtaining optimal results and achieving the most effective change detection, specific spatial, temporal, spectral and radiometric data issues must be understood for all change detection methods. A typical list, for example, according to Coppin *et al.*, (2004), and Millward *et al.*, (2006), would include the following issues:

Temporal resolution

Change detection using satellite images require the temporal resolution to be as similar as possible between the used images. There are two important sensor system temporal resolutions that should be kept almost constant when performing change detection analysis. First, it is best to use similar (same season or month or day) dates for all the remotely sensed data. Second, the remote sensor data used should be obtained from a sensor system that acquired data on same day (or approximately) and in similar

hours of the day. Same hour acquired images eliminate diurnal sun angle effects that can cause anomalous differences in the reflectance properties of remotely sensed data. Clearly speaking, the imagery should be from the same time of year or season, for each date, to account for solar illumination angle effects and to minimize differences in seasonal vegetation cover (regarding the phenological cycle of vegetations).

Spatial resolution

The remotely sensed data must be accurately registered to perform analytical change detection. Images from the same sensor will be easily registered to each other because they have the same pixel size. Pixel size of an image depends on the instantaneous field of view (IFOV) of the sensor system. The IFOV dictates the information content of the remote sensing data. Each pixel in the image represents the average reflectance or emittance of the target on the ground. Therefore, resampling pixels size (to a smaller size) will not yield additional spatial details.

The remote sensor data used in digital change detection should be acquired with approximately the same look angle. For example, Spot sensor systems are pointable and collect data at look angles that are off-nadir by as much as $\pm 20^\circ$. Two Spot images one has 0° off-nadir and another has 20° off-nadir look angles; they might lead to inaccurate results in change detection research, especially in a study an area with forests of tall trees. Images should be co-registered or orthorectified to better than one half pixel accuracy, or 0.5 RMSE (Root Mean Square Error), to minimize spatial offset and distortion effects associated with the geometric registration method used. This registration accuracy is also related to original image pixel size.

Spectral resolution

Remote sensing system has a spectral resolution which the dimension and number of bands in the imagery data. In the ideal situation, the spectral resolution of different remotely sensed data are chosen constant in change detection studies. Analysts should select, otherwise, images of relatively similar bands, e.g., Spot bands 1 (green), 2 (red)

and 3 (near-infrared) can be matched with bands from Landsat MSS bands 1 (green), 2 (red) and 4 (near-infrared).

Radiometric resolution

Radiometric resolution is the sensitivity of the sensor (detector) to record differences for radiant flux emitted or reflected from terrain of interest. The sensors collect, normally, data at 8 bits with values ranging from 0 to 255. This is could be called radiometric precision of a sensor which should be the same in change detection remote sensing data.

Atmospheric conditions

Radiometric normalization may be necessary to remove atmospheric effects – differences caused by scattering and absorption by atmospheric constituents, and by differing solar zenith angles, can falsely mimic change in land cover types, these might include cloud and cloud shadow problems (Coppin *et al.*, 2004).

In other words, atmospheric conditions should be normalized for datasets. Analyst, Therefore, run atmospheric correction models for each dataset in change detection research.

Each of these sources of variability can contribute to an overall commonality between images, enabling analysis at the lowest possible “common denomination” between datasets.

There have been many research studies that developed methods and algorithms for obtaining digital change information, using a wide variety of remotely sensed data. These are summarized in detail by Coppin *et al.*, (2004) and a few are outlined in Table 4. Of those reviewed, linear transformations and image differencing are generally reported to perform better than other bi-temporal change detection techniques and are further discussed below.

Table 4. The different algorithms of change detection analysis.

| Technique | Methodology | Challenges | Advantage |
|---|---|---|--|
| Post-Classification comparison | <ul style="list-style-type: none"> - Independent image classification - Compare on classified images pixel-by-pixel | <ul style="list-style-type: none"> - Results depend on accuracy of original classification | <ul style="list-style-type: none"> - No radiometric processing required - No post change classification required |
| Write function Memory Insertion | <ul style="list-style-type: none"> - Inserting bands from different images (e.g. panchromatic) in red, green and blue planes. - On screen reading of change. | <ul style="list-style-type: none"> - Depends on the capacity of the reader who is seeing the screen. - Possibility of having different combination of bands in order to have results | <ul style="list-style-type: none"> - Mainly effective for aquatic macrophyte detection. |
| Image arithmetic | <ul style="list-style-type: none"> - Uses single or multi-bands from each date. - Band ratioing or subtracting. | <ul style="list-style-type: none"> - Difficulty of having the correct threshold between change and no change pixels. - Ratioing is criticized as being statistically invalid (Riordan, 1981). | <ul style="list-style-type: none"> - Simple. |
| Manual on screen digitizing of change | <ul style="list-style-type: none"> - Uses aerial photos or high-resolution satellite images. - Visual interpretation on CRT screen. | <ul style="list-style-type: none"> - Require high knowledge of the study area. - being able to detect all changes. | <ul style="list-style-type: none"> - Directly seeing the change object and understand it. |
| Image transformation (Bi-temporal linear data transformation) | <ul style="list-style-type: none"> - Uses principal component analysis (PCA) to detect changes. - Variance-covariance matrices are performed to detect uncorrelated images. - Tasseled Cap is also used (Crist and Cicone, 1984). - Multivariate Alteration Detection MAD (Nielsen et al., 2001). | <ul style="list-style-type: none"> - Difficulty in interpreting and labeling the changes. - Require comprehensive knowledge of study area. | <ul style="list-style-type: none"> - Accurately spots the changes. |
| Composite analysis | <ul style="list-style-type: none"> - Statistical difference determined using multistage decision logic. | <ul style="list-style-type: none"> - Complex when applied on multidates. - Demands prior knowledge of logical interrelationships of the classes. - Difficulty in class labeling. | <ul style="list-style-type: none"> - Necessitates only a single classification. |
| Univariate image Differencing | <ul style="list-style-type: none"> - Subtraction of multitemporal imagery, original or transformed data. | <ul style="list-style-type: none"> - Require precise registration. - Highly depend on change/no change thresholding technique. | <ul style="list-style-type: none"> - Simple |
| Change vector analysis | <ul style="list-style-type: none"> - Multivariate change detection that process the full dimensionality of the image data. - Produce: change magnitude and change direction | <ul style="list-style-type: none"> - Requires perfect registration. - Intensive user interaction. | <ul style="list-style-type: none"> - Effective. |
| Image regression | <ul style="list-style-type: none"> - Mathematical model assumes a linear relationship between multitemporal no change data. | <ul style="list-style-type: none"> - Difficulty in threshold definition. | <ul style="list-style-type: none"> - Accounts for atmospherical conditions and sun angle. |
| Multitemporal Spectral Mixture Analysis | <ul style="list-style-type: none"> - Based on differences in high spectral resolution end member. | <ul style="list-style-type: none"> - Requires high spectral resolution imagery. | <ul style="list-style-type: none"> - Provide physically based, standardized measures of fractional abundance. - Detect very fine detailed change (i.e. thinning of forests). |

Conclusion

Globally, the problem of forest fragmentation is increasing due to the growth of population and fluctuations in climatic conditions. Mediterranean forests suffer day-to-day increasing anthropic pressure. This is the case of Lebanon, where all forest types are affected and in all the Lebanese territory. While dense population in one area (coast) is highly fragmenting forests, in other areas, overgrazing is the main problem affecting forests. Like in Mediterranean forests, Lebanon does not have studies on hemerobiotic states of the forests and the main causes of forest fragmentation are not investigated, which keep the danger of forest fragmentation not understood. In parallel with Mediterranean forest decline, Lebanon is witnessing similar trend in decreasing forest resources but with changes in spatial patterns (not studied yet). Landscape spatial analysis is an important ecological parameter that is highly required to be applied for landscapes in Lebanon. Understanding changes of spatial patterns is possible through landscape metrics and remote sensing. In Lebanon, new methodologies are also needed in landscape spatial analysis because of the forest special situations and pressures found. Remote sensing will offer, as in other studies, valuable information that are the basis of landscape spatial analysis. Compared with several studies done in many countries, it is obvious that valuable information can be attained via remote sensing, which are difficult to be done only by the normal methods. No similar study is found in Lebanon.



Part II.

Materials & Methods



Chapter 3

Materials

This chapter introduces the background knowledge on parameters that have a significant influence on forests and landscape spatial patterns. Urban distribution and topographic characteristics are genetically related forests spatial patterns in controlling the shapes and sizes of forest patches, as well as their compositions. Climatic parameters play also important role in forests shaping landscapes. Thus, knowing the urban distribution, topographic complexity and climatic conditions of the area is the first step to be determined before understanding any spatial pattern study. In addition, geomorphology greatly affects forests spatial patterns and affects connectivity. Forest and landcover present important elements where this study focuses. Climate also affects the forest spatial distributions, e.g., precipitation. These parameters were discussed in details, and thus taken as perquisite information in this chapter.

1. Study area

1.1. Geographic location

Situated on the eastern shore of the Mediterranean Sea, Lebanon occupies the junction between Europe, Asia and Africa, with a surface area of 10,452 km². It is characterized by four main geomorphological (physiographical) units as follows (eastward): narrow *Coastal Plain* and two mountainous chains (*Mount Lebanon* and *Anti Lebanon*) separated by a fertile and relatively elevated plateau (700 to 1100 m altitude) named *Bekaa Plain* (Figure 10). They are of northeast to south-west orientation. The two mountain chains occupy around 70% of the Lebanese rugged territory (Table 5).

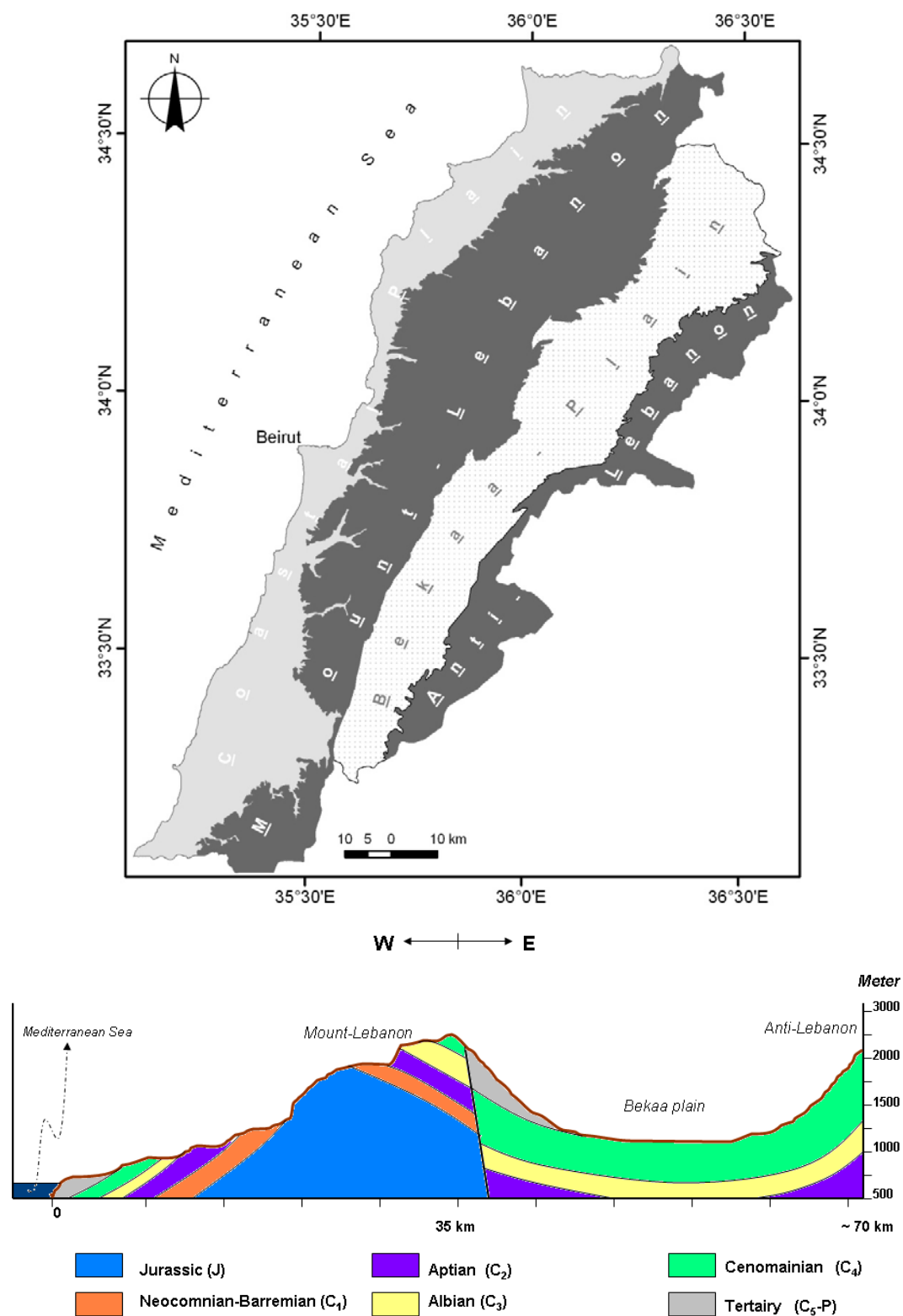


Table 5. Surface coverage of each geomorphological units of Lebanon.

| <i>Geomorphological unit</i> | <i>Landform</i> | <i>Area (km²)</i> | <i>Total (km²)</i> | <i>% of total Lebanese territory</i> | |
|------------------------------|-----------------|------------------------------|-------------------------------|--------------------------------------|----|
| <i>Coastal Plain</i> | Plain or gentle | 1348 | 2848 | 13 | 27 |
| <i>Bekaa Plain</i> | slopes | 1500 | | 14 | |
| <i>Mount Lebanon</i> | Mountainous | 5548 | 7604 | 53 | 73 |
| <i>Anti Lebanon</i> | topography | 2056 | | 20 | |

Besides the general investigation of the forests around Lebanon, in this research we selected a representative area to perform detailed forest spatial pattern analysis and changes. The area of study represents an East-West section along Lebanon (Figure 11). The study area has a significant variability of physical, biotic, abiotic and anthropic conditions. It is almost a rectangular shaped area having 22 km in length and 60 km in width. Thus, it holds a total surface area of approximately 1,363,181.9 ha corresponding to 13% of the Lebanese territory.

The selected area embraces the western two of the four Lebanese physiographic units as a cesarean section across the coastal plain and passing through *Mount Lebanon* where it reaches inland the *Bekaa plain (Bekaa Valley)*. It is situated between latitudes: 34° 09' 00'' N and 34° 21' 36'' N and longitudes: 35° 39' 36'' E and 36° 32' 24'' E. Thus, the study area passes through different major climatic variations starting from the coastal zone eastward where western and eastern flank of *Mount Lebanon* have major environmental differentiations. The two floristic ensembles (Mediterranean and Mediterranean presteppe) found in Lebanon are situated on each side of the mountain within the study area. Eight out of ten bioclimatic zones of Lebanon include in the study area.

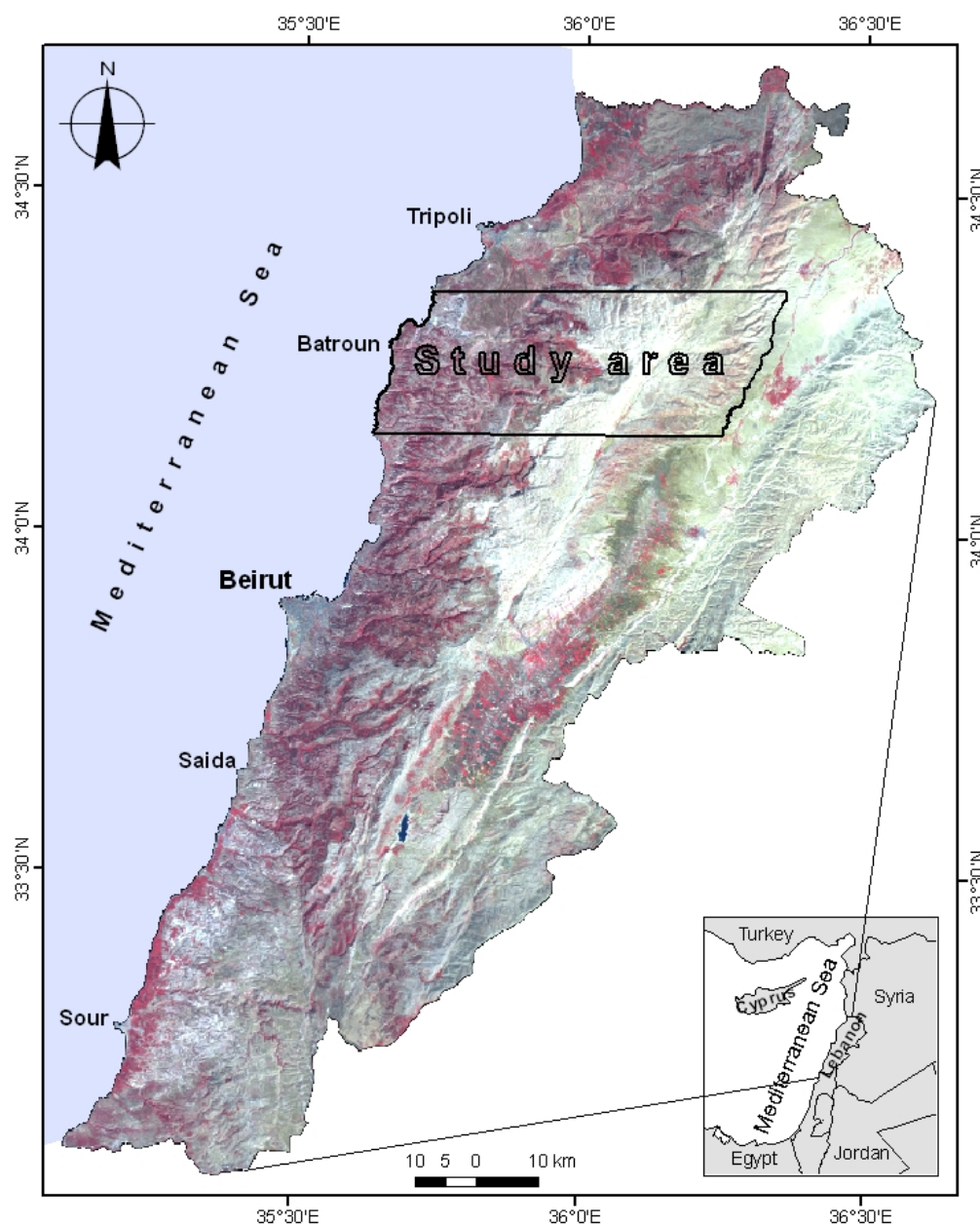


Figure 11. Location of the study area. (Background: Landsat image of 1989, band combination Red = 4, Green = 3 and Blue = 2).

1.2. Climate

Although climatologists distinguish the Mediterranean climate as temperate (Peguy, 1970), ecologists consider it a zone of transition between temperate and tropical climates (Emberger, 1933). This climatological zone (Mediterranean) is specified by the existence

of dry period with various lengths depending on the location around the Mediterranean, which imposes annual stress on vegetations (Quézel and Médail, 2003).

Being on the eastern shore of the Mediterranean Sea, Lebanon is under the influence of the Mediterranean climate with four clearly distinguished seasons, they are: summer (hot and dry), winter (cool and rainy), fall and spring. Fall and spring are two transitional seasons of gradual change of temperature and with little rain.

There are major climatic differences among the different geomorphological units of Lebanon and different microclimatic conditions that are the result of important topographic complexity. Humid summer with little or no rain characterizes the coast, which has a narrow range of temperature because of the sea influence. *Mount Lebanon* screens inlands (eastern slope of Mount Lebanon, Bekaa Valley and Anti Lebanon) from the sea influence. This results in considerably less precipitation and humidity, and wider range of daily and yearly temperatures (inland). Gradual increase in altitude produces colder winter starting from the coast toward Mount Lebanon.

Generally, Lebanon can be divided into three main climatic zones. The coastal zone up to 350 m altitude has a humid climate with direct maritime influence. It is known by its mild temperature that never frosts (except for the very north coast), and with high humidity of 70% annually. The *Mount Lebanon* and the southern part of *Anti Lebanon* (Jabal el Sheikh or Hermon Mountain) have mountain Mediterranean climate (Figure 12). The third climatic zone is the *Bekaa plain* that holds a continental Mediterranean type of climate that is mainly arid and semi arid Mediterranean.

1.3. Precipitation

The precipitation scheme in Lebanon is purely Mediterranean as the seasons of heavy rain are between October to the end of April or sometime to May (on higher elevations). The period comprises between December and Mars responsible for 75-80% of the precipitation. The highest peak of rain occurs in January. The other 20-25% remains for autumn and spring storms. June, July and August are dry months, whereas September might offer rare thunderstorms.

Although winter is the rainy season, precipitation does not fall homogeneously over the season, thus major precipitation falls after December. Rainfall is usually concentrated in few days along winter seasons and falls frequently in heavy cloudbursts. Rainfall rate varies greatly from one year to another.

As mentioned before the climatic barrier (*Mount Lebanon*) creates almost abrupt climatic diversity between western and eastern parts of Lebanon. Thus, terrain properties characterization cause important variations in meteorological conditions at close-by geographical locations. Rainfall, for example, changes when comparing the coast to 20 km inland. Chekka village at an altitude of 15 m demonstrates 880 mm of yearly average rainfall rate (Figure 12). At 30 km inland, Bsharre (1925 m of an altitude) shows 943 mm of precipitation per year. While at 25 km toward laqlouq of 1700 m, the yearly average rainfall reaches 1604 mm. Across the mountain peak, Yammouneh village at 1370 m has 970 mm of rain while after 20 km inland (Baalbeck of an altitude 1150 m) rainfall rate decreases to 403 mm per year.

Starting from the coast, the western flank of Mount Lebanon embraces five narrow (40 km) bioclimatological zones. Similarly, the eastern slope of Mount Lebanon (20 km) is divided into four bioclimatological zones (Abi Saleh, 1978). This expresses the existing climate variability across a horizontal section of Lebanon.

Western slope of *Mount Lebanon*, facing the sea, receives humid air of the southwest (Figure 12). This heavy humid air discharges on this slope with an increasing rate of rainfall (40 mm/100 m) as it is going higher in altitude (Figure 13). However, the trend is descending towards the inner areas with an increasing rate as climbing the *Anti Lebanon* (Plassard, 1971). This presents a precipitation-altitude phenomenon. The decreasing rate when descending the eastern slope of *Mount Lebanon* toward the *Bekaa plain* has 35 mm/100 m. This rate increases by 25 mm/100 m at the *Anti Lebanon*.

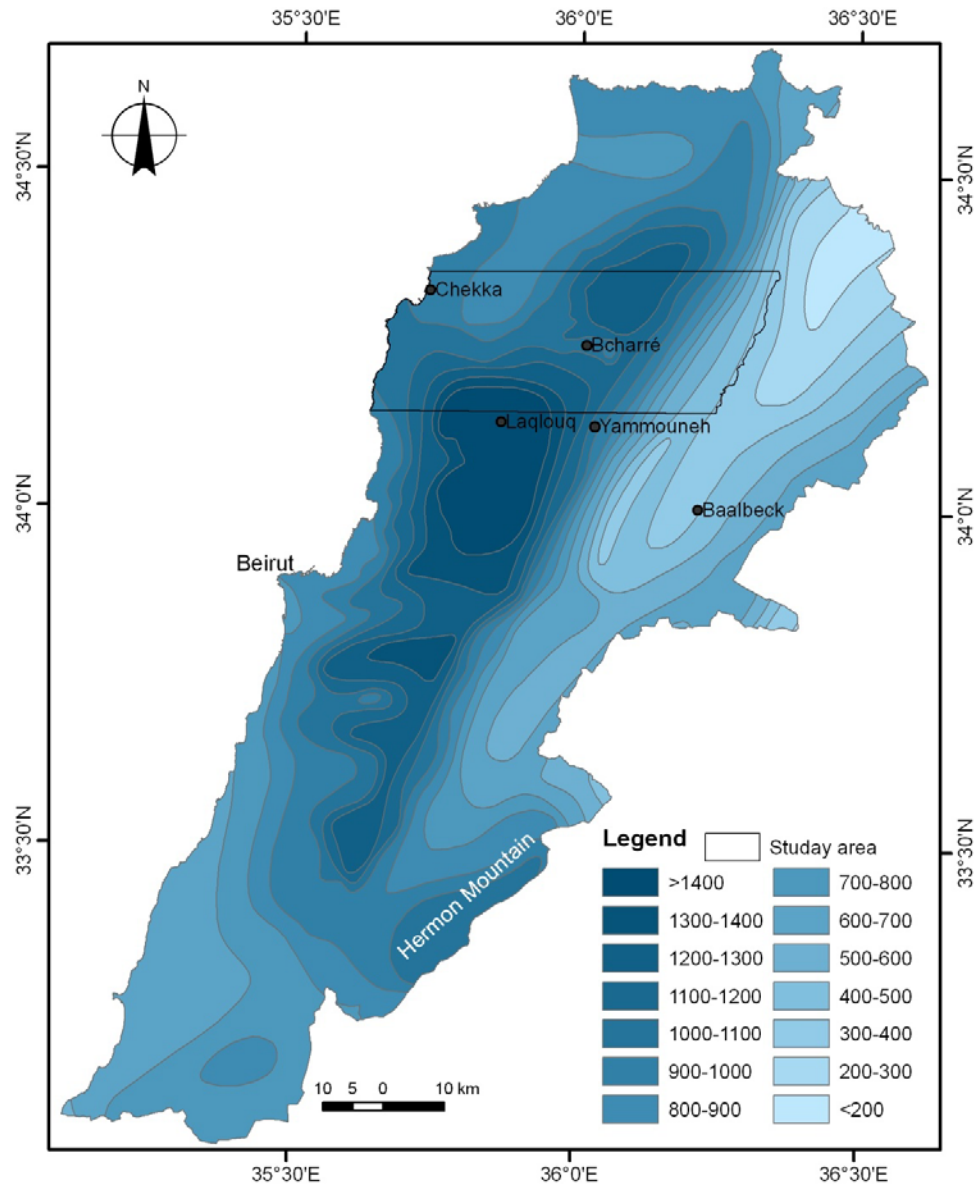


Figure 12. Precipitation rate (mm per year) in Lebanon (based on the precipitation map of Lebanon: Plassard, 1971).

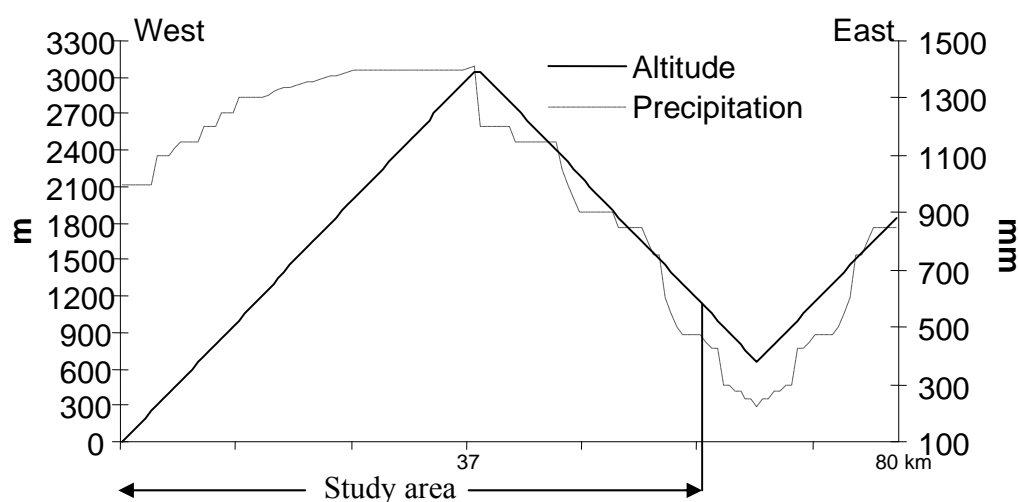


Figure 13. Precipitation-altitude relationship across the study area includes the highest altitude in Lebanon (3080 m).

The number of rainy days is between 60-80 days in *Mount Lebanon* and the *Coastal plain* (Sanlaville, 1977). While, this does not go beyond 50 days in the *Bekaa plain* and stay between 50-60 days at the *Anti-Lebanon*.

Snow as part of precipitation occurs in the study area. The snowfall is known to occupy 1 time/5 years on altitude less than 200 m; 5-10 days/year between 200-1000 m, 30-35 days/year 1000-1800 m and over 50 days/year on altitudes exceeding 2000 m (Hakim, 1985). Snow cover remains at least 120 days/year at 2000 m of elevation or higher. At very high altitude, patches of snow cover might remain 6-9 months or rarely stays the year round in limited and small patches.

1.4. Temperature

As with precipitation, the temperature is an altitude-related process (Figure 14). In the area of concern, the mean annual temperatures are: 21°C on the coast, 15°C at 900 m altitude, 12°C at 1800 m and 5°C at 2700 m. At the higher altitudes of *Mount Lebanon*, this temperature reaches 2 to 4°C. The gradient of temperature with elevation is about 0.6°C/100m. At the *Bekaa plain*, mean temperature ranges between 15 and 16°C while at *Anti Lebanon* higher elevations between 6-9°C.

January is the coldest while August is the hottest month. The thermal amplitude is between 13 and 16°C at the *Coastal plain* and western slope of *Mount Lebanon*. It exceeds the 19° C at the *Bekaa plain*. Inlands, temperatures are very contrasting when comparing winter to summer temperatures.

Frost may occur for more than 100 days at the higher altitudes of *Mount Lebanon*. At The coast, count 1-2 days of ice but only at the very north. Icy days reach 10 at 1000 m elevation and 75 days at the 1800 m. Frost at the oriental slope of Mount Lebanon is accentuated with 123 days at 2500 m altitude. Temperatures might reach -23°C at this elevation as this one-day on (20/01/1964) record shows.

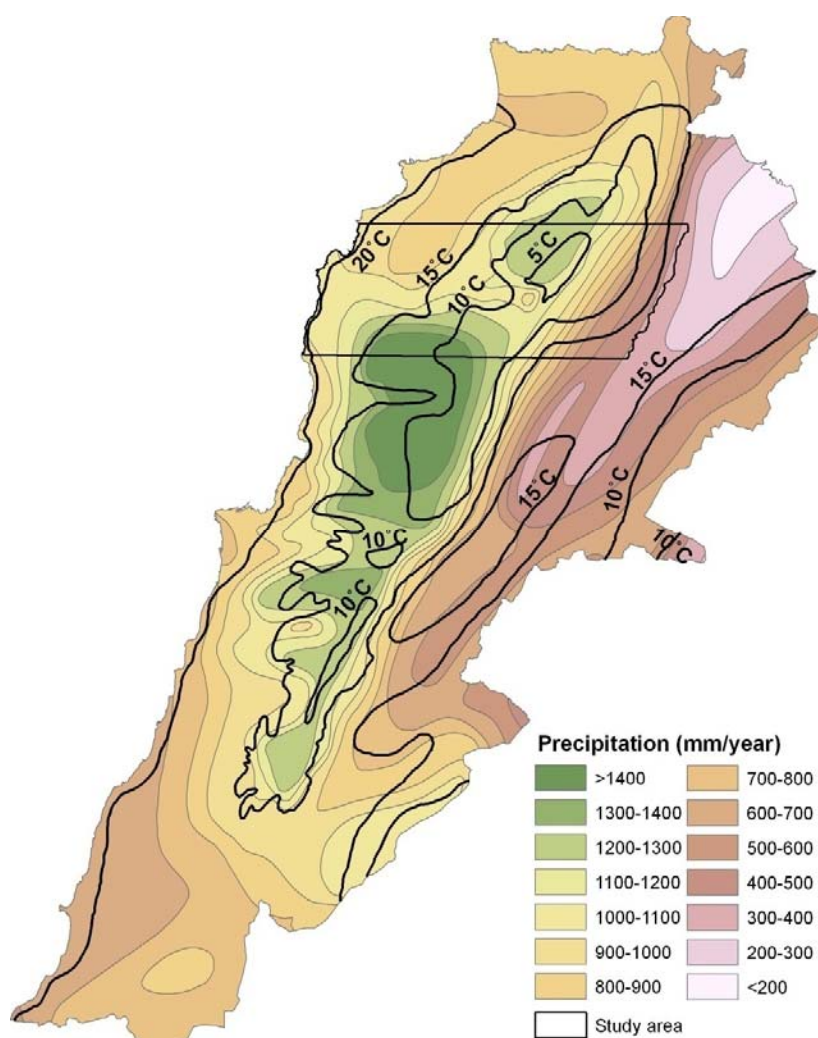


Figure 14. Mean annual temperature depends on altitude as well as yearly rainfall rate (prepared using the “Atlas Climatique du Liban” CAL 1971, 1973 and 1983).

Evapotranspiration

The other principal component of climatic conditions is the evapotranspiration. The way of measuring water deficit in a climate is by knowing the annual precipitation (P) and evapotranspiration (ETP) (Thornthwaite, 1948), particularly the ratio of P/ETP (Quézel and Médail, 2003). Unfortunately, the calculation of ETP in Lebanon is rare. However, local ETP measures show as a norm, it averages about 50% of the precipitated water, and may go up to 75% in dry periods (Jaber, 1995).

Relative humidity

Relative humidity oscillates around 70% at the coast but with little less humidity toward the south. Variations at the mountains are significant and go between 40 to 80% in winter, 40 to 60% in summer. At the middle Bekaa plain, relative humidity varies significantly between winter and summer (75% to 45%).

1.5. Urban distribution

Lebanon faced rapid urbanization and disorganization of urban distribution during the war period from 1975 to 1990, which greatly affected the environment. Peripheral areas around big cities have greatly expanded where urbanization patterns changed dramatically. According to the Ministry of Displaced, about 810,000 citizens were displaced during the war. The total urbanization area, in Lebanon, has increased by 50% between 1962 and 1998 (Figure 15). Total population increased from 2,668,000 (inhabitants) in 1985 to about 4,000,000 by 1997 (Central Administration of Statistics). Large portion of population (around 40%) resides in Beirut. The population density changed from 72 persons/km² in 1932 to 400 persons/km² in 1997.

Population density, around Lebanon, reveals that Beirut city holds the highest population pressure followed by Mount-Lebanon administrative district (Mohafazat). The least population is at the Bekaa and Nabatieh areas (for Mohafazat distributions in Lebanon see Figure 15).

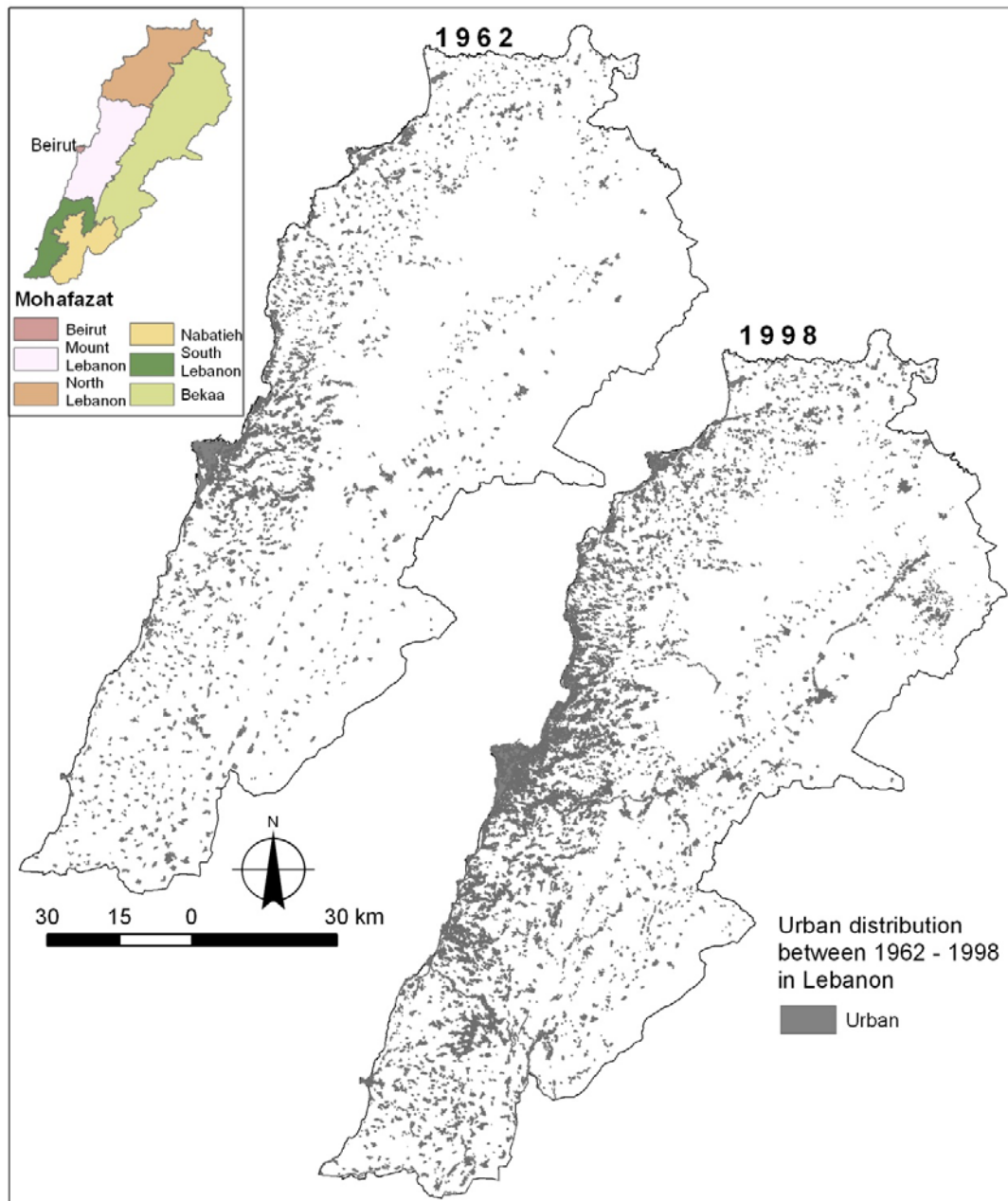


Figure 15. Urban distribution overall the Lebanese territory between 1962 and 1998; Administrative districts in Lebanon (top left) (prepared from topographic maps of 1962 and landcover map of 1998).

The uneven distribution of the Lebanese population is shown in Figure 16.

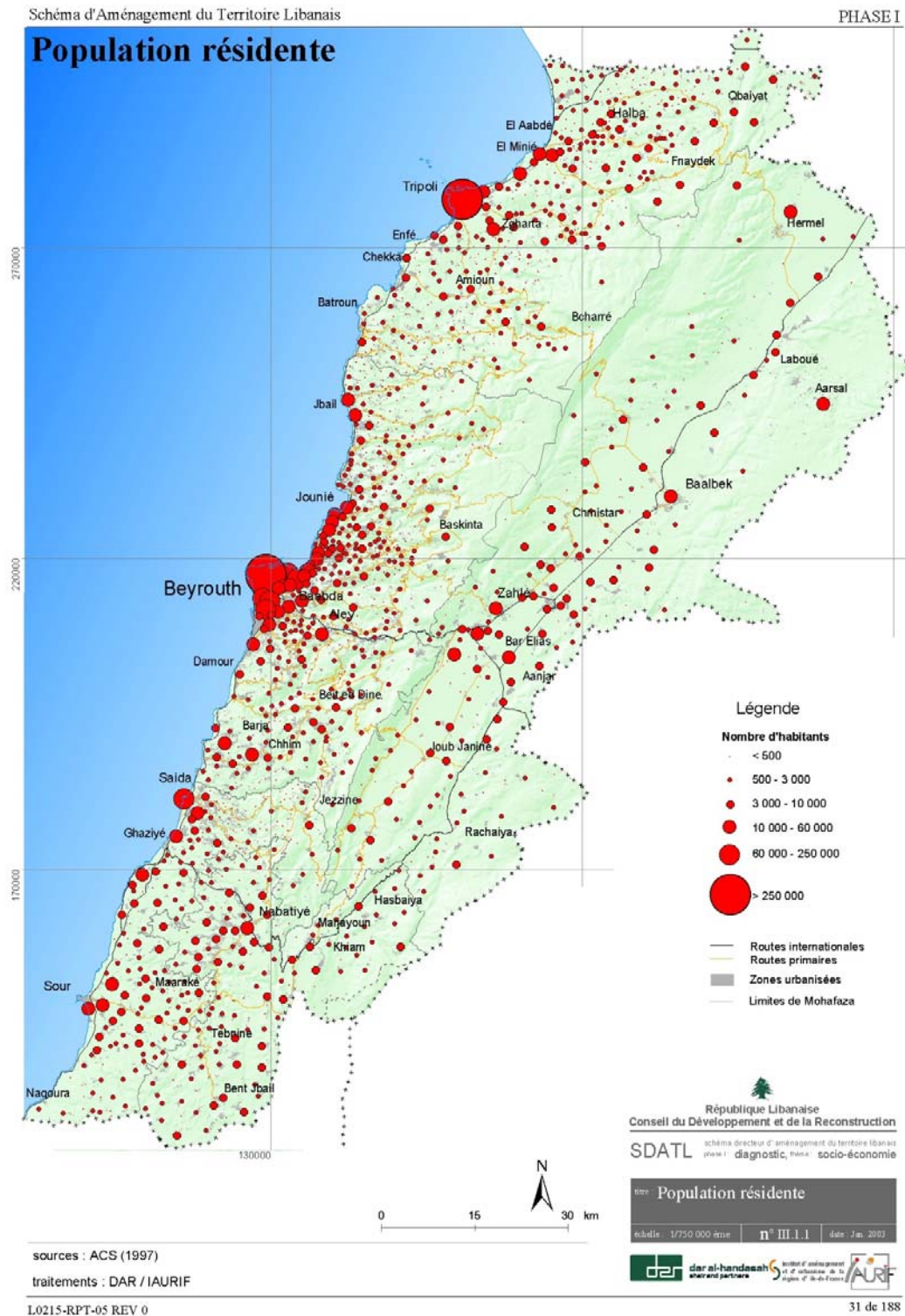


Figure 16. Population distribution over Lebanon (SDATL, 2003).

1.6. Forests and bioclimatic zones of the study area

Vegetations are typically Mediterranean with important variability across the country. The presence of ten spatially narrow bioclimatological zones produces important vegetation diversity. This fact made Lebanon rich in species numbers, especially when considering its limited area compared to other Mediterranean countries. In Lebanon, species number reaches 3761. The main cause behind this vegetation wealth is the complexity in geomorphological characteristics.

The floristic ensembles of Lebanon are: (1) typically Mediterranean and (2) Mediterranean presteppe where they encompass 10 bioclimatic zones (Abi Saleh, 1978) (Figure 17). The study area crosses through the different vegetation zones in Lebanon, capturing a wide range of geo-climatic conditions. The spatial distribution of the narrow bioclimatic ranges along the study area is as follows (according to Abi Saleh and Safi, 1998) starting from sea level inward:

- (1) thermo-Mediterranean, eu-Mediterranean, supra-Mediterranean, mountainous-Mediterranean, oro-Mediterranean, and
- (2) Mediterranean presteppe, supra-Mediterranean presteppe, mountainous-Mediterranean presteppe and oro-Mediterranean presteppe (Table 6 and Figure 18).

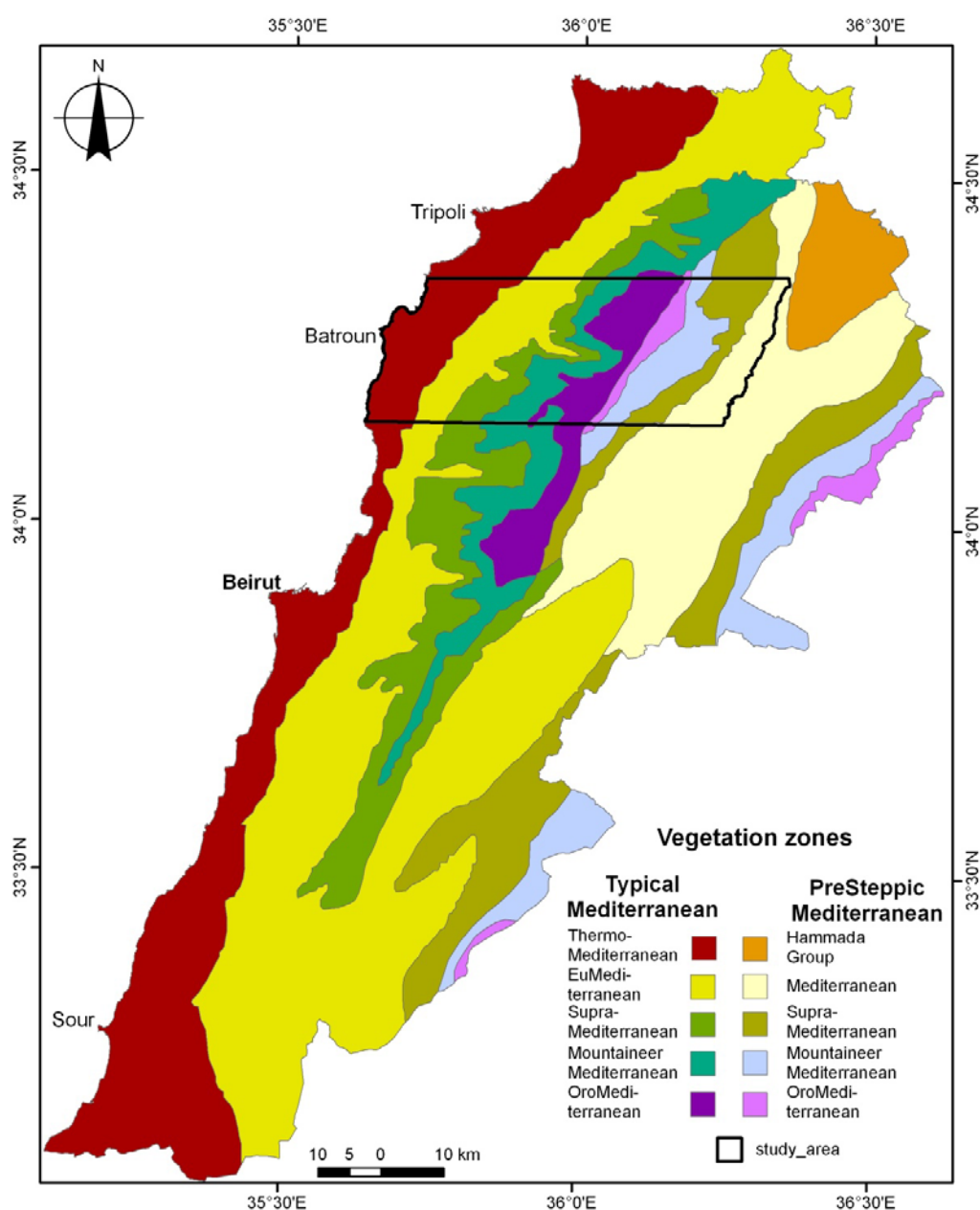
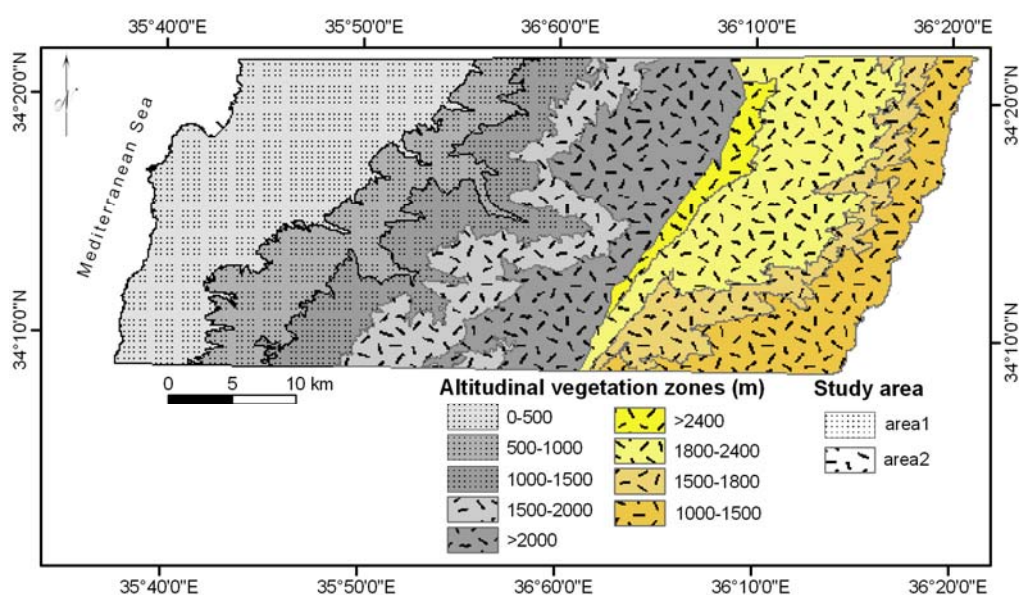


Figure 17. The study area across the main vegetation zones of Lebanon (modified from Abi Saleh and Safi, 1998).

The thermo-Mediterranean bioclimatic level (0-500 m) has the highest coverage (19.3%) within the study area among all the other levels. Presteppe oro-Mediterranean constitutes a limited area of the study surface (Table 6). The majority of the study area (about 66%) is under the typically Mediterranean environment.

Table 6. Distribution of vegetation levels in the study area.

| <i>Floristic ensemble</i> | <i>Vegetation level</i> | <i>Bioclimatic level</i> | <i>% cover</i> | <i>Average width (km)</i> |
|---|--|--------------------------|----------------|---------------------------|
| Mediterranean, Western slope of Mount Lebanon | Thermo-Mediterranean 0-500 m | Sub-humid | 19.3 | 8 |
| | Eu-Mediterranean 500-1000 m | Sub-humid to humid | 15.9 | 3.5 |
| | Supra-Mediterranean 1000-1500m | Humid | 9 | 4 |
| | Mountainous Mediterranean 1500-2000 m | Per-humid | 9.2 | 3.8 |
| | Oro-Mediterranean >2000 m | Per-humid | 12.8 | 9 |
| Mediterranean Presteppe, Eastern slope of Mount Lebanon | Mediterranean presteppe 1000-1500m | Semi-arid | 10.5 | 7 |
| | Presteppe Supra-Mediterranean 1500-1800 | Sub-humid | 9.5 | 3.6 |
| | Presteppe mountainous Mediterranean 1800-2400m | Humid | 10 | 10 |
| | Presteppe oro-Mediterranean >2400 m | Per-humid | 3.8 | 1 |
| | | | | |

**Figure 18. The existing vegetation zones in the study area.**

Successive civilizations have influenced the natural landscapes all over the country, where each forest type provided different services and a tool for life. Cedar forests were mainly used for constructing boats; junipers were the major wood for building home roofs; oaks remain the main source of charcoal production. Naturally, for example, fire burned 451 km² at the northern part of the country (toward the study area) between 1998 and 2000 (ECODIT and MoE/LEDO, 2001). Different disturbances regimes for natural

vegetations could be found between the coast and inland because of their socioeconomic variability.

Utilizing the 1965 forest map of Lebanon, five out of seven forest types of Lebanon are found within the study area, which they are: (1) *Q. calliprinos* Webb., (2) *Pinus brutia* Ten, 3) *Cedrus libani* A. Rich., 4) *Juniperus excelsa* M.B., 5) *Cupressus sempervirens* L.

Three important forest natural reserves constitute a part of the study area. These are:

- (1) “Bcharre cedars” that holds the oldest specimens of *Cedrus Libani* of over 2000 years of age on 2700 m of an altitude. Although Bcharre cedars has limited surface area (about 7 ha), it was nominated world heritage area by the Society for the Protection of Nature in Lebanon. Bcharre natural reserve has been set for tourism purposes since the 1940ies and was protected by law in late nineties.
- (2) “Horsh Ehden” of 450 ha surface area and altitude ranging between 1200 and 2000 m. This nature reserve passes through three vegetation levels where you may find oaks, cedars and junipers. Horsh Ehden was included into conservation as a natural reserve after issuing the law number 121 on March 9, 1992.
- (3) “Tannourine” holding mainly cedars on an area of 1200 ha. It is the largest cedar forest area in Lebanon holding 316,645 trees of cedars and other –conifers and broadleaves- (Khater and Abboud, 2007). It was created under the law number 9 on February 1999.

1.7. Geomorphology

Landscape analysis, which is among the main purposes of this research, is genetically related to geomorphic features of terrain. Geomorphology is the study of the origin and evolution of topographic features and it is based on the principle that all landforms can be related to particular geologic processes.

The study area has rugged topography (Figure 19). To the north of the area, profile number 1 shows longer distance of lower elevation next to sea. This area becomes shorter when moving southward.

Four topographic profiles across the study area show abrupt changes in topography. The coastal slope of the mountain has obvious changes in gradient, i.e., it continuously breaks.

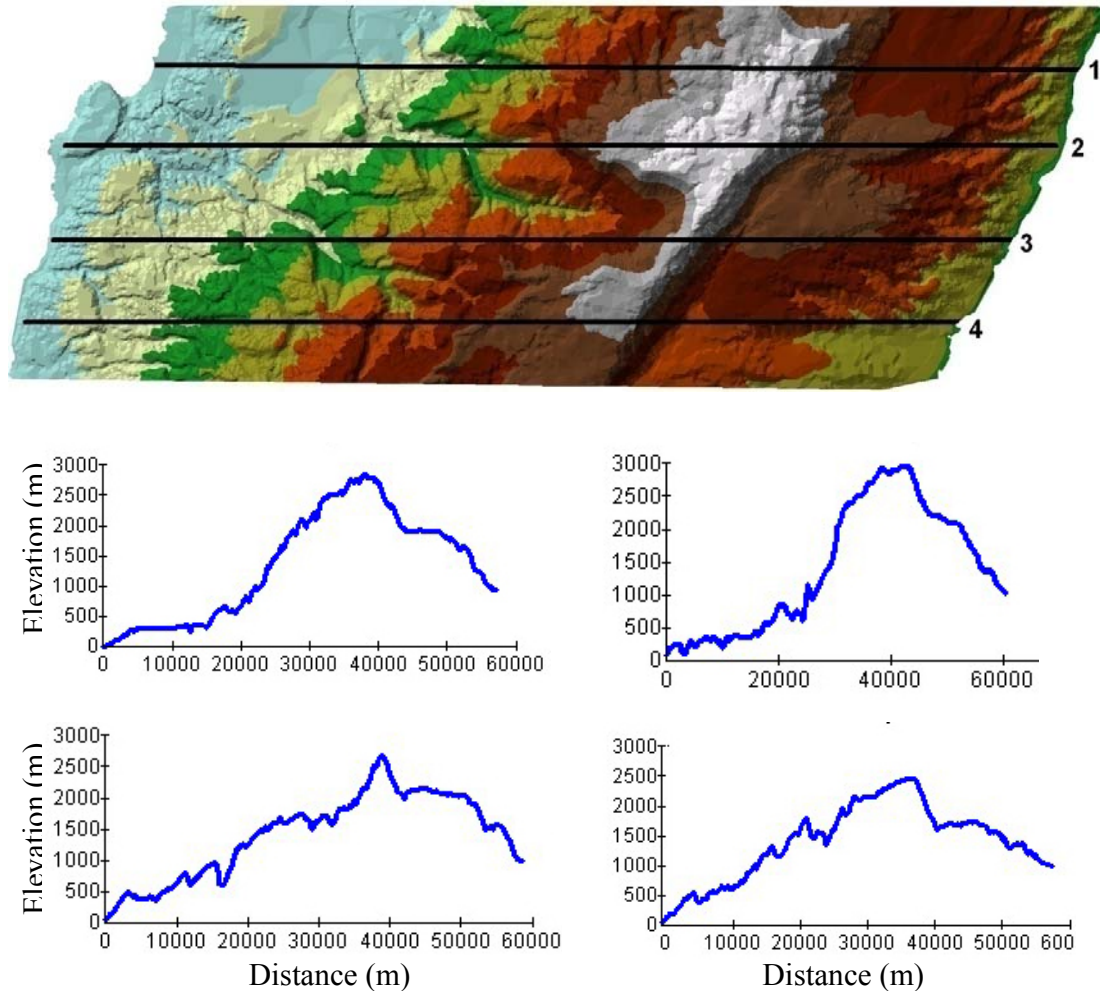


Figure 19. Topographic profiles along the study area (1 to 4).

The area of study encompasses a miscellany of geomorphic features, which are determined mainly by the geologic structures and rock types, as well as climatic conditions (Table 7).

Table 7. Distribution of various landforms at the study area.

| <i>Geomorphic and dimensional characteristics</i> | <i>Coastal plain</i> | <i>Mount Lebanon</i> |
|---|--|------------------------------------|
| Area (km²) | 15 | 1375 |
| West-East Width (km) | <1 to 1.5 | 40-50 |
| Mean altitude (m) | 25 | 1400 |
| Topographic surface | Fine, irregular shore line | Rugged |
| Slope gradient (m/km) | <5 | 60-65 |
| Slope direction | West (seaward) | West and East |
| Rock type | Quaternary deposits (loose materials) | Carbonates (+ other hard rocks) |

Coastal plain

Generally the coastal plain in Lebanon is narrow (i.e. <5km) with NE-SW direction. This plain goes to little wider than 10 km at the north-west corner of Lebanon (plain of Akkar). It reaches its minimum width in the study area, where the mountain is in direct contact with the sea. This is clear along the stretch connecting Borj-Jbeil, Terouil, Baachta, Heloue, Ouata, Dawrat and Madfoun and also at Batroun. In some places, beach sands cover this plain, whilst alluvial deposits appear as cultivated regions.

The slope is almost gentle, except in places where the mountain in direct touch with the sea, thereby, abrupt elevated terrain masses are observed.

Along this plain, a number of valleys exist. Most of them are of the consequent type, as they follow the terrain slopes. Some of these valleys are attributed to intermittent watercourses (streams); while others are related to permanent streams.

Mount Lebanon

This geomorphic unit represents the largest portion of the study area (Table 2) and holds a number of morphologic features. The area represent a ridge that trends in the NE-SW direction and has slopping exposures (facing east and west) that are divided by the crests (north-south direction). These crests form a line connecting Qernet Es-Saouda (3083 m), the highest point in the Middle East, Jabal El-Mnaitra (2702 m), and Jabal Sannine (2628 m). They actually divide Lebanon to the west of the crest (littoral part) with slope direction seaward and to the east (inner part) with slope direction to the *Bekaa plain*. The width of the western slope is about 40 km and of the eastern slope around 10 km. Therefore, this unit comprises asymmetrical folded terrain (geologically the so-called monoclinic structure), with eastern and western limbs.

The abrupt elevated areas and sharp slopes, because of complicated geologic structures, express the rugged topography of this unit. However, valleys of different shapes and scales are known. Gorges of sharp edges are tremendous, notably in hard rock masses. While, this feature is not exactly the case in the eastern exposure.

Karstification is a remarkable surface feature that characterizes the area, as result of water dissolution. Hakim (1985) estimates that around 65% of the terrain in Lebanon is karstified with different scales and shapes. In the study area this features are located on surface and subsurface. For the surface ones, lapis, Karnes, cylindrical holes and furrows characterize the carbonate rocks situated below 1500 m altitude (Shaban, 2003). Whilst, above this altitude, and in addition to the former ones, surface depression, called sinkholes, are exist. Beside, the subsurface karstification is expressed as cavities and deep galleries.

1.8. Geology

Geology expresses the rock formation and characteristics. It is a major component in the physical parameters that influencing the landscapes. It shapes the physiography of an area and influence biodiversity. Two major branches, lithology and structure, represent geology. Lithology describes the rock type and textures, notably its interior composition, while structural is particularly concerned with deformations of rock body and with different rock masses positions.

Almost all rocks in Lebanon are sedimentary (pale of carbonate rocks), except a unique sandstone formation and some local volcanic ones. However, lithology at the study area is representative for the country. The oldest rock formation that exists in the area is attributed to the Middle Jurassic. The study area is bordered by the regional “Yammouneh” fault from the east (Figure 20).

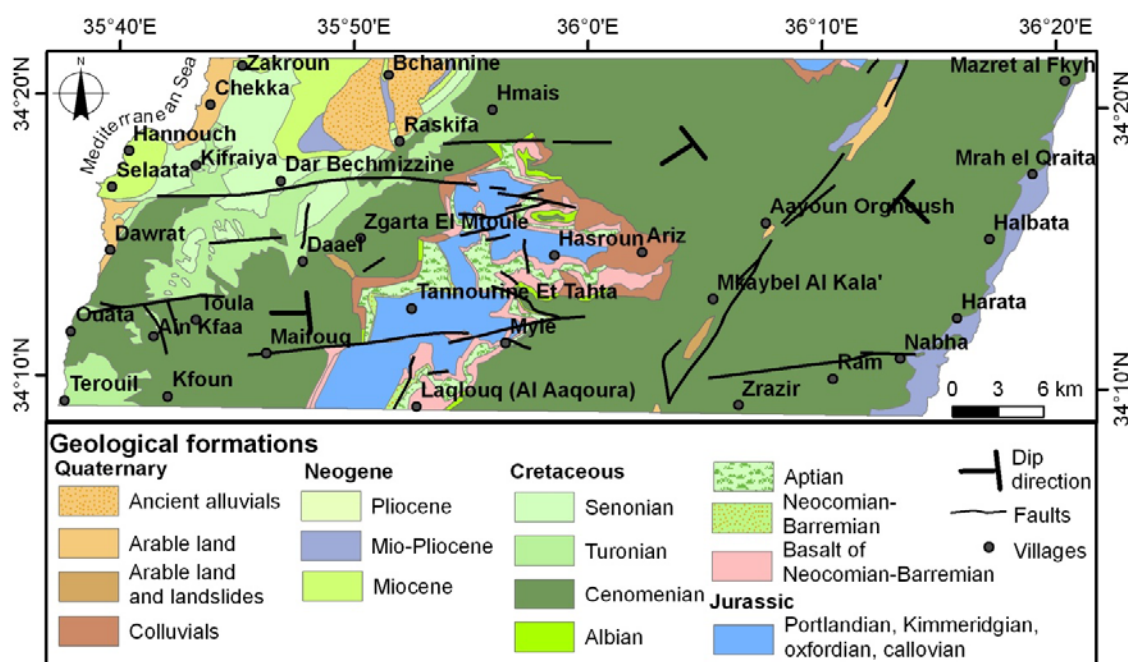


Figure 20. Geological characteristics of the study area.

The geology of the study area was investigated previously through local, national and regional studies such as Dubertret (1953 and 1966) and Hakim (1985).

Several rock types are exposed in the area. They are of different physical and chemical characteristics. There are the sedimentary rocks (Jurassic and Cretaceous), Tertiary (Nummulitic and Neogene) and Quaternary (fluvial, alluvial and colluvial deposits). Within fifteen geological formations, 65% are of carbonate rocks of different lithological characteristics (see Table in annex I). These carbonate rocks are mainly of limestone (CaCO_3) and dolomite $\text{CaMg}(\text{CO}_3)_2$ as the most widespread lithologies.

The geographic distribution of the exposed rock formations in the area is structurally controlled. This is obvious from the existing faults (huge rock breaks), which serve as lithologic boundaries between different rock types. The majority of these faults, as the major structural features, are of lateral displacement type. Furthermore, the vegetation cover is well reflected from the type of the underlying rocks, e.g., pines on sandstone lithology (Abi Saleh, 1978).

For the geologic structures, the area represents a regional anticline (fold structure). The prevailing dip of rocks has different directions depending on rock deformations; whereas

the Yammouneh fault has a principal role. The area is cut by a number of faults. Some of these faults are several kilometers long, i.e., >25 km, notably in the western mountain chain, where they cross diagonally to Yammouneh fault (Figure 20). In addition, numbers of fracturing systems (local fractures and breaks within the rocks) are developed, especially in the hard rock types. These fractures are a result of the influencing faulting processes. Other folded structures also exist at different categories and scales. All of these structural features are well developed in the area, except in the Bekaa plain, where they are almost covered by soil deposits. (See annex I for more details about the geology of the study area).

1.9. Soil

Soil genesis has two main components the parent materials and the climate. Geomorphology plays also a major role in soil formation. Other factors are considered secondary like water, vegetation and human (Gèze, 1956). Soil types in the Mediterranean region do not differ much from that formed in temperate areas (Quézel and Médail, 2003). The most important relation resides between the Mediterranean soil types and the climate is the large contrast and alternation of rainy winter and dry summer.

Studies on the soil types of Lebanon started in the fifties (Gèze, 1956). However, the work was performed on a small spatial scale (1/200,000). After finishing his map, Gèze considered that a spatially detailed classification of the soil is highly required. Darwish *et al.*, (2006) has performed the soil map of Lebanon on 1/50,000 spatial scale. Soils characterizing the study area are mostly the red soils covering more than 47% of the region (more details on soils in the study area are listed in annex I).

Conclusion

Number of influencing parameters controls a landscape spatial pattern study. Knowing the characteristics of these parameters helps understand forest resources fragmentation. These parameters are either natural or due to human impact. In the study area, human interference and topography are the major parameters that are easily identified from previous work and from existing maps. Urban settlements are frequently found on the

coast. The topography and geomorphology changes rapidly at very short distance. The area is divided into number of vegetation levels (based on climatic and topographic characteristics) where forests are distributed. Vegetation levels are very narrow (strip like forms) which complicate the forest spatial patterns. Another essential parameter is the geomorphology. In occidental Lebanon (coastal part), the predominant slope direction seaward influences the water availability for forests which greatly reflects on oak forest characteristics. Steep valley thus induces a number of steep-sided valleys, which affect the forest patch shapes and size. An important parameter is the landcover/land use, which is a dynamic element in forest fragmentation assessment. The climate is another related parameter in water studies. The existence of a climatic barrier (i.e. the elevated mass of Mount Lebanon) results in a high divergence between coastal and inland part of the study area. The coast receive considerable precipitation rate while the other side of the mountain is characterized as a semiarid zone.

2. Available data

2.1. The investigated periods and the used data

The investigated period was dated back to the oldest spatial forest data of Lebanon that ever existed, i.e., the 1965 forest map of Lebanon. This forty years old forest map is, therefore, the base data used for this research. Other forest data was extracted from satellite images, as a principal part obtained by this research, and existed landcover maps for Lebanon, mainly the 1998 landcover map. Landsat TM images of the study area are available for the years 1972 and 1989. Other satellite sensors are Spot 5 of 2003 and IKONOS of 2005 were also available. Periods of the investigations are not equally distributed along the past years (Figure 21). Spot 5 satellite image of 2003 was made available for this research thanks to the laboratory LADYBIO-CNRS, France.



Figure 21. Time scale and periods for landscape analysis and forest change investigation at the study area depending on data availability.

However, another important investigation was accomplished for the entire territory of Lebanon. In this part of the research, we only used the 1965 forest map and the landcover map of 1998. Satellite images were not available for the entire country and even though may be available as Landsat images, it will require a long time of field verification, which would take longer than a thesis work.

The used data on this research were categorical maps and satellite images (Figure 21). Field visits were also performed. The categorical maps are the 1965 forest map, 1998 landcover map and topographic maps. Satellite images are of four different sensors: Landsat MSS of 1972 and Landsat TM; Spot 5 (Satellite Pour l'Observation de la Terre) of 2003 and IKONOS of 2005 (Figure 22).

In this research, GIS (Geographic Information System) was mainly performed using ArcGIS version 9.2 for ESRI for all processes. Remote sensing image treatments were established using ERDAS Imagine version 8.7 software. Landscape spatial indices were

computed using Patch Analyst 3.1 of FRAGSTATS interference on ArcView 3.2 GIS software.

Materials used

| Categorical data | Satellite images | Software | Field-onsite |
|---|------------------|-------------------|---------------------------------|
| 1965 forest map | Landsat MSS 1972 | ArcGIS 9.2 | Global Positioning System (GPS) |
| | Landsat TM 1989 | Erdas Imagine 8.7 | Digital camera |
| 1998 landcover map | Spot 5 of 2003 | Patch Analyst 3.1 | |
| Topographic map of 1962 (1/50,000 and 1/20,000) | Ikonos 2005 | ArcView 3.2 | Survey sheets |
| | | | |

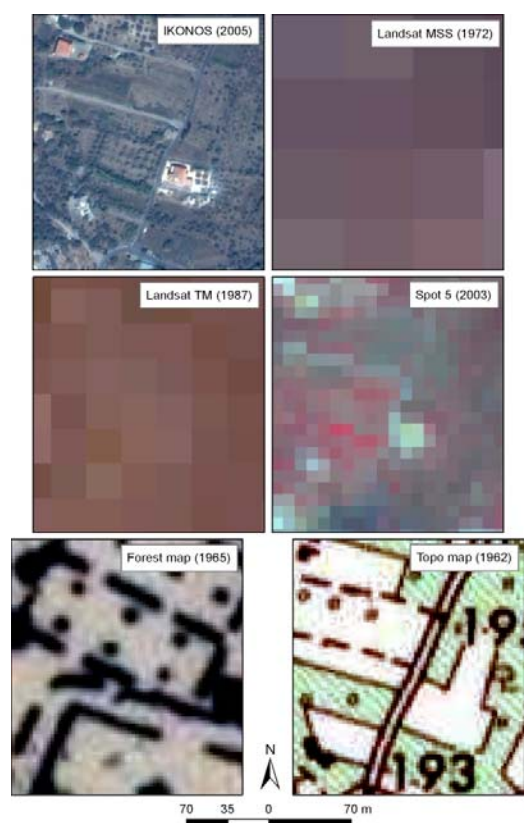


Figure 22. Different used materials; and the original datasets used have varying spatial resolution and include MSS (80 m), TM (30 m), IKONOS (0.80 m) and Spot 5 (10 m) images. Forest map (1/50,000)and topographic (1/20,000) were also used.

2.2. Categorical data

In the frame of this research, we relied on the following categorical data.

Topographic map of Lebanon

The 1962 country aerial mission is the base data used to produce the topographic maps of Lebanon (DAGG, 1963). Thus, these maps have the same source of data as for the 1965 forest map. The topographic maps also have 1/50,000 spatial scale which made it directly comparable to the forest map. Six out of twenty-seven topographic sheets of Lebanon cover the study area. The six sheets are identical to the 1965 forest map where they cover the study area. Another topographic map of 1963 was also used which has 1/20,000.

Forest map of 1965

The 1965 forest map of Lebanon is among the foremost records of the forests spatial distributions (El Husseini and Baltaxe, 1965). The country first aerial mission of the year 1962 was the main source of data for the creation of this map. The aerial photos has 1/25,000 spatial scale, which provided the map authors the capability of reaching 1/50,000 spatial level of details. Visual interpretation and stereoscopic analyses were used to produce this map. The map consists of 27 sheets covering the whole country. The study area covers 6 sheets namely from Norwest to Southeast: Batroun, Tripoli, Sir Ed Danniye, Jbeil, Qartaba and Baalbeck. These sheets were scanned and digitized using the facilities of the geographic information system (GIS). Out of the eight forest types listed on the forest map, six were found within the study area: oak coppice, oak standards, *Pinus brutia*, Cedar, Juniper and Cypress (Table 8)¹.

¹ We recorded the forest type names exactly as they are listed in the map legends.

Table 8. Legend of the 1965 forest map (El Husseini and Baltaxe, 1965)¹.

| # | Forest type | Canopy closure (%) | Species mentioned |
|---|---------------------|--|--|
| 1 | Oak coppice | >30 | <i>Quercus calliprinos</i> , <i>Q. infectoria</i> , with or without some <i>Pinus brutia</i> , <i>Juniperus sp</i> and in varying portions |
| | | 10-30 | |
| 2 | Oak standards | >30 | <i>Quercus calliprinos</i> , <i>Q. infectoria</i> , <i>Q. brantii</i> , <i>Q. cerris</i> |
| | | 10-30 | |
| 3 | <i>Pinus brutia</i> | Predominantly regeneration or pole stands | Rarely <i>Pinus halepensis</i> |
| | | >40 | |
| | | 10-40 | |
| 4 | <i>Pinus pinea</i> | Predominantly regeneration or pole stands | - |
| | | >40 | |
| | | 10-40 | |
| 5 | Cedar | >40 | <i>Cedrus libani</i> with or without <i>Q. spp</i> , <i>Juniperus spp.</i> , and <i>Abies silica</i> , in varying portions |
| | | 10-40 | |
| 6 | Fir | 10-40 | <i>Abies cilica</i> and <i>Juniperus spp.</i> With or without <i>Cedrus libani</i> , <i>P. brutia</i> , and <i>Q. spp.</i> In varying portions |
| 7 | Juniper | >30 | <i>Juniperus excelsa</i> , <i>J. foetidissima</i> , with or without <i>Quercus calliprinos</i> and <i>Q. infectoria</i> in varying proportions |
| | | 10-30 | |
| 8 | Cypress | Small isolated occurrence denoted by small circle like shape | <i>Cupressus sempervirens</i> usually in mixture with <i>P. brutia</i> |

Landcover map

Up to date, Lebanon has two landcover maps, one belongs to the year 1987 (FAO, 1990) and another correspond to 1998 (MoA/MoE, 2002). The first one (paper map) had 1/50,000 scale; while the second is on digital format at 1/20,000 scale. Albeit, a 1/50,000 scaled landcover map is our requisite for nearly direct comparison of maps, the 1987 map holds very general legends with regard to forest cover that makes it of minimum link with the previous forest map of 1965. Indeed, the 1987 landcover map shows some exaggeration in forest areas and other landcover spatial accuracy. On the other hand, the 1998 landcover map has detailed forest legends that make it eligible for possible comparison with 1965 forest map. The scale and legend differences between both maps, however, hinder direct comparison. Solving this difficulty is not an easy task and requires knowing the establishment methods of the original map before any treatments. The origin of the landcover map of 1998, therefore, was first investigated then its legends related to forest were examined.

Origin of 1998 landcover map

The landcover map of 1998 was derived from IRS-1D –Indian satellite (panchromatic 5 m spatial resolution) and Landsat TM 5 (30 m spatial resolution) satellite images. The IRS-1D image was merged to bands 2, 4 and 7 of the Landsat TM 5 one, using the Principle Component Merging method. This process produced a False Color Composite (FCC) image.

A number of ancillary data supported the visual interpretation of the merged satellite images that enhanced the production accuracy. The ancillary data are the topographic map (DAGG, 1963), landcover map of Lebanon (FAO, 1990), aerial photographs covering part of north Lebanon in 1999 (Ministry of Agriculture, Lebanon), Landcover map of the coast at 1/50,000 scale (for north coastal area and 2000 for south one) and field verifications. The working scale was set to 1/10,000 in order to produce the final landcover map at 1/20,000 scale.

The legends were elaborated under the supervision of the Land Cover Classification System (LCCS) software developed by FAO. The LCCS is an international recognized comprehensive standardized classification system designed to meet specific use requirements and create maps at different scales. It is a hierarchically phased classification that meets almost any mapping purpose. Legends concerning forests on the 1998 landcover map were separated between coniferous, broadleaved and open mixed woodlands with their coverage-density (Table 9).

Table 9. Forest legends as plotted on the landcover map of 1998.

| General forest type | coverage | Forest types |
|----------------------|----------|---|
| Coniferous Woodland | Dense | <i>Pinus pinea</i> , <i>Pinus Brutia</i> , <i>Cedrus libani</i> , <i>Cupressus sempervirens</i> , <i>Abies cilicica</i> |
| | Clear | <i>Pinus</i> spp., <i>Cedrus</i> spp, <i>Juniperus</i> spp., <i>Abies</i> spp., <i>Cupressus</i> spp. |
| Broadleaved Woodland | Dense | Mixed woodland |
| | Clear | <i>Quercus</i> spp., Other type of broad leaves |
| Open mixed wood land | Clear | Mixed wood land |

Forest map of 2005

The 2005 forest map uses the same patches of the 1998 landcover map. This means that the 2005 forest map and the landcover of 1998 have the same landscape spatial

configurations. We used the field data collected in the creation of this map but only spots located at the study area. They conducted a detailed species investigation of forests and herbs (MoA and FAO, 2005a,b).

2.3. Satellite images

Spot (Satellite Pour l'Observation de la Terre) satellite was first launched in 1986 as Spot 1 and followed with others within the last two decades (Table 10). We used multispectral Spot 5 satellite image of 2003.

Table 10. SPOT satellites launching date and current state.

| Satellite | Operating date | Current state |
|-----------|--------------------|-----------------------------|
| Spot 1 | April 22, 1986 | Not in use |
| Spot 2 | January 22, 1990 | Operating |
| Spot 3 | September 26, 1993 | Failure since November 1996 |
| Spot 4 | Mars 24, 1998 | Operating |
| Spot 5 | May 4, 2002 | Operating |

The spatial and radiometric resolution of Spot satellites justifies their engagements in numerous environmental applications (Girard and Girard, 1999) (Table 11).

Table 11. Spot 5 (instrument 2HRGs) satellite characteristics.

| Satellite | Spectral bands | Ground pixel size | Spectral range |
|-----------|---------------------|-------------------|-----------------|
| Spot 5 | → 2 Panchromatic | 2.5 m or 5 m | 480 to 710 nm |
| | → B1: Green | 10 m | 500 to 590 nm |
| | → B2: Red | 10 m | 610 to 680 nm |
| | → B3: Near Infrared | 10 m | 790 to 890 nm |
| | → B4: SWIR | 20 m | 1580 to 1750 nm |

Spot orbits in quasi-polar direction, circular, phased and sun-synchronous (average altitude: 822 km, inclination: 98.7 grades and 1 h 41 min 24 s period). A polar orbit in conjunction with the rotation of the earth around the polar axis, the inclination of the orbit plane (98.7 degrees, i.e., near-polar orbit) allows the satellite to fly over any point of the earth during a 26 days cycle after 369 revolutions (orbit revolutions per cycle). Spot 5 has imaging swath of 60x60 km x 80 km, and image dynamics of 8 bits.

Preprocessing operations, sometimes referred to as image restoration and rectification, are intended to correct for sensor and platform-specific radiometric and geometric distortions of data. We used Spot 5 images that were preprocessed to the level-1A, which is manipulated by Spot operators before vending the images. Level-1A preprocessing leaves the data in raw form. Level-1A data are intended primarily for users requiring image data that have undergone only minimal preprocessing (i.e. no geometric and radiometric correction but application of a linear model to compensate for instrument effects).

The study area falls within the Spot 5 worldwide reference system paths and rows 118/281 and 120/282. Three scenes of Spot 5 multispectral images of 10x10 m pixel size (no panchromatic band) were acquired in 2003 on June 24 (scene 1), July 07 (scene 2), and August 15 (scene 3) were used to cover the entire study area (Table 12), i.e., In other words, the study area lies on fractions of three Spot 5 scenes.

Table 12. Characteristics of the used Spot scenes.

| Scene parameters | | Scene 1 | | | |
|---|----------------------------|----------|----------|------------------|--|
| Scene ID | 5 120-282 | | | | |
| K-J identification | 120-282 | | | | |
| Date | June 24, 2003 (08:26:54.6) | | | | |
| Instrument | HRG 1 | | | | |
| Shift along track | 0 8 | | | | |
| Preprocessing level | 1A | | | | |
| Spectral mode | 4 | | | | |
| Number of spectral Bands | | | | | |
| Spectral band indicator | HI1 | HI2 | HI3 | HI4 | |
| Gain number | 4 | 3 | 3 | 3 | |
| Absolute calibration gains (W/m2/sr/μm) | 1.080450 | 1.054000 | 1.172000 | 6.411000 | |
| Orientation angle | 13.241888 degree | | | | |
| Incident angle | R6.836533 degree | | | | |
| Sun angle | Azimuth | | | Elevation | |
| | 119.444858 degree | | | 71.378114 degree | |
| Number of lines | 6000 | | | | |
| Number of pixels per line | 6000 | | | | |
| Scene center location | Latitude | | | Longitude | |
| | 33° 54' 34" N | | | 36° 5' 30" E | |
| Scene parameters | | Scene 2 | | | |
| Scene ID | 5 118-281 | | | | |
| K-J identification | 118-281 | | | | |
| Date | July 07, 2003 (08:26:40.3) | | | | |
| Instrument | HRG 1 | | | | |
| Shift along track | 0 0 | | | | |
| Preprocessing level | 1A | | | | |
| Spectral mode | J | | | | |
| Number of spectral Bands | 4 | | | | |
| Spectral band indicator | HI1 | HI2 | HI3 | HI4 | |
| Gain number | 2 | 1 | 1 | 1 | |
| Absolute calibration gains (W/m2/sr/μm) | 0.719010 | 0.632822 | 0.704489 | 3.788901 | |
| Orientation angle | 13.006393 degree | | | | |
| Incident angle | R10.562752 degree | | | | |
| Sun angle | Azimuth | | | Elevation | |
| | 123.509854 degree | | | 68.461340 degree | |
| Number of lines | 6000 | | | | |
| Number of pixels per line | 6000 | | | | |
| Scene center location | Latitude | | | Longitude | |
| | 34° 24' 6" N | | | 36° 41' 22" E | |
| Scene parameters | | Scene 3 | | | |
| Scene ID | 5 119-281 | | | | |
| K-J identification | 119-281 | | | | |
| Date | August 15, 2003 (08:26:38) | | | | |
| Instrument | HRG 1 | | | | |
| Shift along track | 0 0 | | | | |
| Preprocessing level | 1A | | | | |
| Spectral mode | J | | | | |
| Number of spectral Bands | 4 | | | | |
| Spectral band indicator | HI1 | HI2 | HI3 | HI4 | |
| Gain number | 1 | 1 | 1 | 1 | |
| Absolute calibration gains (W/m2/sr/μm) | 0.540540 | 0.632822 | 0.704489 | 3.788901 | |
| Orientation angle | 13.302812 degree | | | | |
| Incident angle | R6.680238 degree | | | | |
| Sun angle | Azimuth | | | Elevation | |
| | 135.799413 degree | | | 64.168787 degree | |
| Number of lines | 6000 | | | | |
| Number of pixels per line | 6000 | | | | |
| Scene center location | Latitude | | | Longitude | |
| | 34° 24' 7" N | | | 36° 13' 17" E | |

Other satellite images

The Landsat images are MultiSpectral Scanner MSS (acquired on 09/15/1972), (Landsat images was obtained from Global landcover network, Environment and Natural resources service SDRN, Research, Extension and training Division, Sustainable development department, FAO).

Satellite image IKONOS (RGB-pan-sharpen) of June 2005 was also used. The image has 80 cm spatial resolution and it was orthorectified with a DEM (Digital Elevation Model) of 10 m. The relative accuracy is between 1-5 m.

2.4. Field survey

Field visits were performed throughout the study area (Figure 23). One hundred ninety six site locations and field observations were registered between 2005 and 2006, using Trimble GeoExplorer GPS unit (Global Positioning System). Field sites were documented (name and date) and recorded with digital photo. Field survey format was filled onsite to assess plants and geomorphological information. For example, among the recorded geophysical data are slope gradient and aspect, lithology and soil type. The forest overall density was estimated using scale of 1 (lower density) to 6 (higher density). Plant species were surveyed for woods and main herbaceous plants found within a forest patch. As an example, some field survey sheets are demonstrated below (Table 13): Field surveys strategy followed the different vegetation levels across the study area and covering representative forest types within each of these levels.

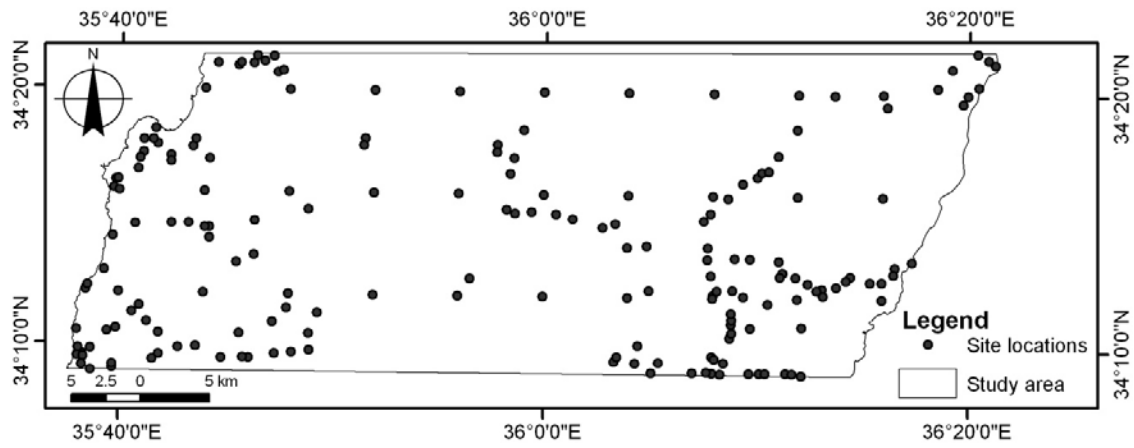


Figure 23. Field observation points over the study area.

Table 13: Field survey sheets.

| Site | Code | date | location | | | Slope gradient | | | | Slope Exposition | | | | | | | Cover Density | | | | | |
|------------------|------|------------|--------------|--------------|-------|----------------|-----|-----|-----|------------------|----|----|---|---|----|----|---------------|---|---|---|---|---|
| | | | X | Y | Z (m) | 0° | 15° | 40° | 70° | N | NE | NW | W | S | SE | SW | 1 | 2 | 3 | 4 | 5 | 6 |
| Koubba El Bourj | N1 | 27/04/2005 | 35.664455 | 34.274183 | 101 | | | x | | | | | | | | x | | | | | | x |
| Hamat airport | N2 | 27/04/2005 | 35.679975 | 34.280797 | 222 | | | x | | | | | | | | x | | | | | | x |
| Nadi es | N3 | 27/04/2005 | 35.68398 | 34.291538 | 176 | | | x | | | | | | x | | | | | | | x | |
| Bouqat younane | N4 | 27/04/2005 | 35.69525 | 34.297277 | 225 | x | | | | | | | | | | | | | | | x | |
| Bouqat younane | N5 | 27/04/2005 | 35.69525 | 34.297277 | 225 | x | | | | | | | | | | | | | | | x | |
| Chekka | N6 | 29/04/2005 | 35.70563 | 34.289583 | 154 | | x | | | | | | | | | x | | | x | | | |
| Chekka | N7 | 29/04/2005 | 35.705933 | 34.28595 | 197 | | | x | | | | x | | | | | | | | x | | |
| Chekka | N8 | 29/04/2005 | 35.705933 | 34.28595 | 197 | | | x | | | x | | | | | | | | | | x | |
| Kefraya | N9 | 29/04/2005 | 35.722988 | 34.2954694 | 226 | | | x | | | | | | | | x | | | | | x | |
| Kefraya | N10 | 29/04/2005 | 35.724975 | 34.300422 | 242 | | | x | | | E | | | | | | | | | | x | |
| Bednayel | N11 | 29/04/2005 | 35.736083 | 34.287666 | 326 | | | x | | | | x | | | x | x | | | | | x | |
| Rehane | N12 | 3/5/2005 | 35.63453056 | 34.16335278 | 53 | | | x | | | | x | | | | x | | | | x | | |
| Ijdabra | N13 | 4/5/2005 | 35.67822375 | 34.24494167 | 234 | | | x | | x | | x | | | | x | | | | | x | |
| Ijdabra | N14 | 4/5/2005 | close to N13 | next polygon | 245 | | | | x | | | | | | | x | | | | x | | |
| Bejdarfel | N15 | 4/5/2005 | 35.706675 | 34.24563889 | 360 | | | | x | | | | | x | | | | | | x | | |
| Bejdarfel | N16 | 4/5/2005 | 35.73612222 | 34.243 | 390 | | | x | | | | x | x | | | | | | | x | | |
| Zen (El Batroun) | N17 | 4/5/2005 | 35.77153056 | 34.22531667 | 770 | | | x | | | | x | | | | | | | | x | | |

Table 13: continue.

| Code | Lithology | Soil type | Landcover Type | | | | |
|------|-----------|----------------------------|----------------|-------|-------|-------|----------------|
| | | | Forest | Shrub | Grass | Rocks | Others |
| N1 | J6 | shallow | | x | | | |
| N2 | limestone | red soil (relatively deep) | x | | | | olive |
| N3 | j6 | Lithic | x | | | | |
| N4 | c5 | Rendzina | x | | | | |
| N5 | c5 | Rendzina | x | | | | edge of forest |

| | | | | | | | |
|-----|-------|--------------------|---|---|---|--|----------------------------------|
| N6 | c5 | Rendzina | | | x | | Annuals, vegetables |
| N7 | c5 | Rendzina | x | | | | remaining forest |
| N8 | c5 | Rendzina | x | | | | remaining forest |
| N9 | c4 | red to brown soils | x | | | | remaining forest spots |
| N10 | C4/C5 | red to brown soils | | | | | olives |
| N11 | c4 | red to brown soils | x | | | | olive terraces, remaining forest |
| N12 | C4-c5 | Lithic | x | x | | | almond and bare rocks |
| N13 | C4 | Lithic | x | | | | Quercus |
| N14 | j6 | lithic | x | | | | Quercus |
| N15 | j6 | Lithic | x | | | | Quercus |
| N16 | J6 | Lithic | x | | | | Quercus |
| N17 | j6 | red soil | x | x | | | Quercus |

Table 13: continue.

| Site: | Koubba El Bourj | | | | | | Code: | N1 | date | 27/04/2005 |
|-------------------------------|----------------------|---|---|---|---|---|------------|----|---------------------|------------|
| | Braun Blanquet scale | | | | | | Height (m) | | canopy diameter (m) | |
| Species name | 1 | 2 | 3 | 4 | 5 | 6 | | | | |
| <i>Pistacia palestina</i> | | | | x | | | 1.5 | | 1 | |
| <i>Quercus calliprinos</i> | | | | | x | | 1.2 | | 2 | |
| <i>Ceratonia silqua</i> | | | x | | | | 1.5 | | 3 | |
| <i>Stachys distans</i> | | x | x | | | | | | | |
| <i>Phylleria latifolia</i> | | x | | | | | 0.5 | | 0.5 | |
| <i>Myrtus communis</i> | | x | | | | | 0.5 | | 0.5 | |
| <i>Sarcopoterium spinosum</i> | | | x | | | | | | | |
| <i>Rhamnus cathartica</i> | x | | | | | | 0.5 | | 0.5 | |
| <i>Origanum syriacum</i> | | x | | | | | | | | |
| <i>Allium neapolinatum</i> | x | | | | | | | | | |
| <i>Rubus tomentosus</i> | x | | | | | | | | | |
| <i>Asparagus acidifolius</i> | x | | | | | | | | | |
| <i>Dactylis glomerata</i> | | x | | | | | | | | |
| <i>Andropogon distachyus</i> | x | | | | | | | | | |
| <i>Rubia tenuifolia</i> | x | | | | | | | | | |

| | | | | | | | | | |
|------------------------------|---|---|--|--|--|--|--|--|--|
| <i>Callycotome villosa</i> | x | | | | | | | | |
| <i>Phagnalon rupestre</i> | | x | | | | | | | |
| <i>Smilax aspera</i> | | | | | | | | | |
| <i>Hypericum thymifolium</i> | | x | | | | | | | |
| <i>Oryzopsis mliaceae</i> | | | | | | | | | |
| <i>Daucus sp</i> | | | | | | | | | |
| <i>Carduus argentatus</i> | | | | | | | | | |
| <i>Arum sp.</i> | | | | | | | | | |

Table 13. Continue.

| | | | | | | | | | | |
|-------------------------------|-----------------------------|----------|----------|----------|----------|----------|-------------------|-----------|----------------------------|------------|
| Site: | Hamat (airport) | | | | | | Code: | N2 | date | 27/04/2005 |
| | Braun Blanquet scale | | | | | | Height (m) | | canopy diameter (m) | |
| Species name | 1 | 2 | 3 | 4 | 5 | 6 | | | | |
| <i>Quercus calliprinos</i> | | | | | | x | 5 | | 10 | |
| <i>Ceratonia siliqua</i> | | | | x | | | | | | |
| <i>Pistacia palestinea</i> | | | | x | | | | | | |
| <i>Callycotume villosa</i> | | | x | | | | 3 | | 2 | |
| <i>Asparagus acutifolius</i> | | x | | | | | | | | |
| <i>Smilax aspera</i> | | x | | | | | | | | |
| <i>Rubus tomentosus</i> | x | | | | | | | | | |
| <i>Helichrysum Sanguineum</i> | x | | | | | | | | | |
| <i>Dactylis glomerata</i> | x | | | | | | | | | |
| <i>Daucus carota</i> | x | | | | | | | | | |
| <i>Quercus infectoria</i> | | x | | | | | 2 | | | |
| <i>Sarcopoterium spinosa</i> | | x | | | | | | | | |
| <i>Cistus creticus</i> | | x | | | | | | | | |
| <i>Rubia tenuifolia</i> | x | | | | | | | | | |

Chapter 4

Methodology

This chapter describes the methodologies that were followed in order to obtain detailed landscape spatial pattern analysis of forests in Lebanon. Some methods were applied as used in similar studies but many were developed for the purpose of the study and because of the special characteristics of the study area. It aims to end up with appropriate methods that can be applied to assess forest fragmentation and to perform future monitoring. Thus gaps in information and methods were overcome. It tackles quantitative metrics related to forest resources and landscape patterns using satellite images and other data sources. Forest fragmentation analysis was first accomplished for the entire country. Only two data sets were used to accomplish this first part of the research (forest map of 1965 and landcover map of 1998). The spatial characteristics of the forest were investigated such as: (1) forest fragmentation analysis (dividing Lebanon to coastal and inland parts), (2) investigating forest relation to abiotic and edaphic factors in order to understand if forest fragmentation is natural (related to already fragmented abiotic factors) or related anthropic causes, (3) trying to find correlation between landscape metrics (shape, size and where we also used new index called patch strip like form) and monitoring of forest loss and degradation, and (4) investigating the transition changes of landcover between inside previous forest patches.

This whole country forest investigation was an entrance toward detailed forest analysis at a representative study area of Lebanon. Satellite images of Landsat MSS (1972), Landsat (1989) and Spot 5 (2003) together with forest map of 1965 and landcover map of 1998 were used for landscape spatial pattern analysis. In this step, forest map of 1965 was spatially corrected to topographic map of 1/20,000 spatial scale. Regeneration of forest was investigated using new developed methodology for this research. Regeneration of forests was considered to affect the fragmentation analysis, where regeneration analysis draws more understandable and complete view of landscape spatial pattern analysis. Sign of hemerobiotic effects on forest was considered to affect fragmentation. A new method was developed to study the degree of hemerobiotic related to forests. NDVI (Normalized Difference Vegetation Index) was computed to study forest recovery after natural or

anthropic degradation. This feature of fast recovery would greatly affect landscape analysis. Previous study included the topographic complexity of the studied area into distance calculation, which did not produce comprehensive view of the topographic effect on landscape analysis. However, we developed a new method to study the complexity of the topography and its effect on landscape pattern analysis. Finally, it was found that juniper forests (*Junipers excelsa*) are overestimated by circulating a patch on widely distanced trees. This fact also greatly affects the landscape spatial analysis. Therefore, we introduced a new thinking for juniper forests spatial representation that will solve this problem evermore.

The spatial scale used for the entire study is 1/50,000 with 1 mm² minimum mappable unit, i.e., the smallest delineated forest patch is 50 x 50 m or 2500 m².

1. Preparation phase

1.1. Categorical maps

a. Forest map of 1965 and landcover map of 1998

The 1965 forest map of Lebanon has 1/50,000 spatial scale, and constitutes 27 sheets (El Husseini and Baltaxe, 1965). The map was only available as a hard copy. First, the sheets were scanned and entered into a GIS environment under ArcGIS 9.2 software (Environmental Systems Research Institute, "ESRI").

After scanning, the maps were geometrically corrected to fit the Lambert Conformal Conic projection, which is the original map projection. Forest polygons were redrawn in vector format by tracing the lines of the scanned and georeferenced images. The digitization was performed on 1/25,000 fixed spatial scale on a GIS environment because our research is performed on 1/50,000 spatial scale. Each polygon (forest patch) was assigned and attributed according to the forest and the legend type listed on the maps (Figure 24). The GIS vector layers were prepared for direct comparison. Digitizing was performed for the whole set of sheets, i.e., for the entire country. The map was converted to grid format with pixel size of 50 m. Grid format help to perform the most analytical requirements included in the spatial configuration software.

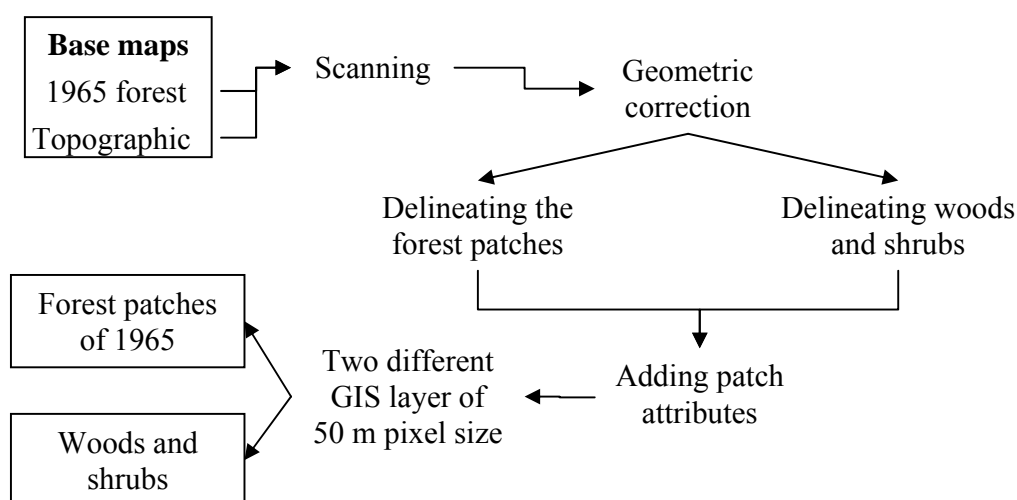


Figure 24. Preparation forest GIS layers from the 1965 forest and topographic maps.

The landcover map of 1998 was first converted to grid format of 20 m pixel size. This layer was then resampled and degraded to 50 m pixel size that facilitates the comparison with other 1/50,000 spatial scale data (Staus *et al.*, 2002).

b. Topographic maps

Topographic maps were scanned and georeferenced according to the grids shown on the maps themselves. The projection is Lambert Conformal Conic. Topographic maps of Lebanon were two sets of different spatial scales: 1/50,000 and 1/20,000. Topographic maps were used to extract forest delineations that were shown as patches of woods and shrubs. Roads and urban settlements were also extracted from topographic maps of higher spatial scales. Contour lines of 10 m equidistance were digitized from the 1/20,000 scaled maps.

Six topographic sheets cover the study area on 1/50,000 spatial scale. They are from west to east: Batroun, Tripoli, Jbail, Sir Ed Danieh, Qartaba, and Baalbeck (DAGG, 1963). On 1/20,000 spatial scale, seventeen sheets cover the study area namely: Enf , Dedd , Zgharta, Danni , Marj-Hine, Turkmane, Batroun, Amioun, Ehd n, Bsharr , Jbab Al Homr, Wadi-Faara, Bej , Douma, Hasroun, Ainata and Nabha.

1.2. Satellite images preprocessing

Preprocessing of satellite images commonly comprises a series of sequential operations including image rectification, subsetting and radiometric correction (Figure 25). The ensemble of image treatments and processing operations has been realized under the facilities of ERDAS[®] IMAGINE[®] software version 8.7.

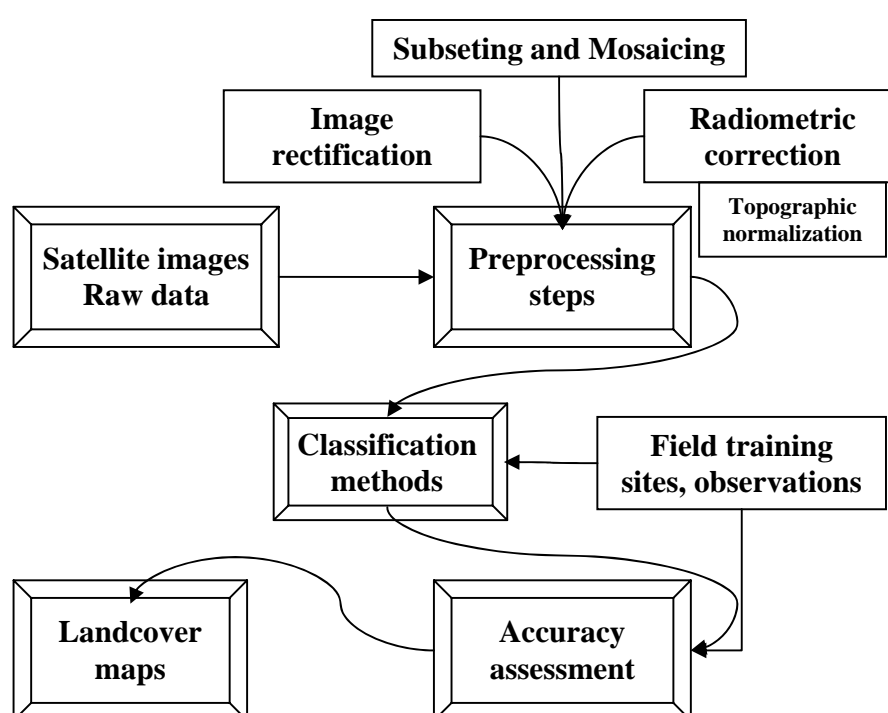


Figure 25: Followed steps to obtain forest cover map.

Image orthorectification

Raster scenes are created and stored in rows and columns-geometry in raster format without any geographical relations. Geometric correction changes the form and geographical location of the image-pixels. Orthorectification is required to correct variation in the surface of the earth and the distortion from tilt of the sensor. Satellite image are affected by systematic sensors and platform-induced geometry errors, which introduce terrain distortions when the image sensor is not pointing directly at the Nadir location of the sensor. The study area has high diverse topographic features, which forced us to perform orthorectification for the images. The pixels of orthorectified image will

not align with pixels of the original image. Orthorectification create a planimetric image at every location with consistent scale across all parts of the image. Orthorectification is the process of stretching the image to match the spatial accuracy of a map by considering location, elevation and sensor information. Orthorectified image require resampling, which is the process of extrapolating data values for the pixels on the new grid from the values of source pixels. Orthorectification of the images was performed, using ArcGIS 9.2 software.

The prepared topographic maps of 1/20,000 spatial scale (as mentioned earlier) were used in geometric corrections. The DEM was built from 10 m contour lines extracted (digitized) from the 1/20,000 topographic map. This DEM was introduced for orthorectification.

Image to map geometric registration was applied. Identical points in both sources (satellite image and topographic map) were identified especially road crosses rivers and some other morphological structures. The first order polynomial mathematical model transformation was used for image rectification. The RMS error was brought to 0.5 of a pixel. The resampling method was the nearest neighbor. The satellite images were resampled and degraded to a pixel size of 50 m in order to harmonize spatial scale and make it comparable to the maps of 1/50,000 spatial scale (Staus *et al.*, 2002).

The first order transformation is a linear transformation. It is used for data that are already projected onto a plane (*ERDAS Field Guide*TM, 2003), e.g., SPOT and LANDSAT. The nearest neighbor transfers the original data values without averaging them; therefore, the extremes and subtleties of the data are not lost. This characteristic in used resampling method is important when discriminating between vegetation types (Jensen, 1996).

Image subsetting

The satellite scenes were larger enough to cover the study area. They required subsetting that means cutting and limiting the images to include only the geographic extension of the study area. The limit of the study area was first prepared into a vector format to facilitate satellite image subsetting. Then the vector format was transformed to

an Area Of Interest (AOI) for subsetting the scenes. Subsetting the scenes has an advantage of putting fewer loads on the computer (as bytes) for further image analysis.

Topographic correction and normalization

The satellite images were also topographically corrected. Mountain regions, such as the study area, often cause radiometric distortion (topographic effect) on satellite images. Topographic effect results from the differences in illumination due to the angle of the sun and the angle of the terrain. This causes a variation in the image brightness values. Topographic effect is a combination of incident illumination (the orientation of the surface with respect to rays of the sun), existence angle (the amount of reflected energy as a function of the slope angle), surface cover characteristics rugged terrain with high mountains or steep slopes (Hodgson and Shelley, 1994). The topographic effects were reduced by applying transformations based on the Non-Lambertian reflectance model and insertion of digital elevation model (DEM). Terrain elevations image of 10 m pixel size were obtained using 10 m equidistant contour lines. The model makes the image appear as if it was a flat surface (Colby, 1991).

Non-Lambertian reflectance model assumes that the observed surface does not reflect incident solar energy uniformly in all directions. This model considers the variation in the terrain and landcover.

Radiometric correction to exoatmospheric reflectance

The process of converting DN-values (Digital Number) to reflectance is called radiometric correction. The DN-value consists of a series of bits. Each bit records an exponent of a power 2 and each DN value records 8 bits. Therefore, the DN-values in a satellite image ranges from 0 to 255. The DN-value is sufficient for examining relative brightness or for visual interpretation but it should be converting to radiance or reflectance for further image analysis. This conversion needs the knowledge of sensor calibration data. Different sensors use different equations for the radiometric correction to reach the exoatmospheric reflectance.

Atmospheric corrections were considered unnecessary because the final classification image is to be used for comparison purposes rather than for change detection analysis (Bernstein, 1983).

This correction might treat variations in the pixel intensities (DNs) that are not caused by the object. The variations include: (1) differing sensitivities or malfunctioning of the detectors, (2) topographic effect, and (3) atmospheric effect.

- Spot 5 satellite image and Landsat TM 5

The first step is converting the DN value into spectral radiance. This step requires information on the *gain* and *bias* of the sensor in each band, in which the operators of the satellite system calculate them. However, there are considerable amount of information that is provided at the image header file. The Lmin and Lmax are the two radiance parameters for each band is given in $\text{mW cm}^{-2}\text{sr}^{-1}$. The conversion of each band to radiance uses this equation:

$$L = \text{Bias} + (\text{Gain} \times \text{DN}) \text{ in } \text{mWcm}^{-2}\text{sr}^{-1}\mu\text{m}^{-1}$$

The calculation of gain and bias was processed using the Lmin and Lamx for each Landsat band. The equations are

$$\text{Gain} = \frac{L_{\max}}{254} - \frac{L_{\min}}{255} \text{ where } L_{\min} = \text{Bias}$$

The next step is conversion of spectral radiance to exoatmospheric reflectance (ρ). The ρ relates the above calculated radiance (L) to the solar irradiance incident at the top of the atmosphere and is expressed as a decimal fraction between 0 and 1

Spot 5 satellite image was converted into radiance using the following equation (This equation calculates the reflectance on the outside of the atmosphere, i.e., surpassing the atmospheric effect):

$$\rho_x = \frac{\pi d^2 L}{E_{\text{sun } x} K_x \cos \theta_s}$$

where

ρ_x is the band reflectance ($0 < \rho_x < 1$),

d is the distance between the sun and earth ($0.9833 < d < 1.0167$ atmospheric unit) varies with the day,

L Spectral radiance at sensor aperture in $\text{mWcm}^{-2}\text{sr}^{-1}\mu\text{m}^{-1}$,

$E_{sun\ x}$ is the solar radiation for the band x of the sensor,

K_x is Calibration coefficient of the band x (gain),

θ_s is solar zenith angle (in radians)

$E_{sun\ x}$ and K_x are given with the image header folder information for each band. The distance calculation could be obtained though the following equation:

$$d = 1 + 0.0167 \left(\sin \left(\frac{2\pi(J - 93.5)}{365} \right) \right)$$

where J is the number of days counted within a year.

Image mosaicking

The study area is enclosed into three spot scenes. The scene number one (check table 12) is toward the coastal part of the area and it reaches an altitude of 1700 m. The scene number two covers 90% of the study area. The other 5% is covered by the third scene.

As it was shown in table 12, the scenes are acquired in different dates. Therefore, before any mosaic process the images must be normalized and corrected, so they have similar or homogeneous DN values as well as histogram matching.

We choose not to stitch the scene number one with the others, which minimize errors that might evolve out of radiometric correction and homogenizations. Each of the scenes were analyzed and treated separately. The obtained outcome (classified image) was joined to other classified scenes.

IKONOS satellite image

Concerning the IKONOS image of 2005 was used to extract detailed information on landcover (e.g., Millington *et al.*, 2003). The preprocessing steps were subsetting and georeferencing only.

2. Global changes

2.1. Forests overall Lebanon

- Forests of Lebanon

This step was performed only between the forest map of 1965 and the landcover map of 1998. The total surface area of each forest type was first computed. Second, configuration analysis was performed using landscape indices, which helped to examine the fragmentation processes on the investigated years. Lebanon was divided between coastal and inner land areas where the coastal area is what includes the Mediterranean vegetation ensemble and the inner area includes the Mediterranean presteppe vegetations.

Forest fragmentation in different parts of Lebanon

We examined nine landscape indices to compare forest fragmentations between coastal and inner lands of Lebanon. Class level landscape indices includes the patch number (PN), mean patch size (MPS), edge length (EL), mean nearest neighbor (MNN), largest patch index (LPI), area weighted mean patch dimension (AWMPFD) and total edge (TE), as they were largely used (Iverson, 1988; Tischendorf, 2001).

Nevertheless, the comparison between coastal and inner land forests was conducted with regard to forest patch size. The forest patches were separated into four groups according to sizes as follows: <50, 50-100, 100-150, 150-200 and >200 ha. The number of patches for each size was also investigated.

Factors of forest-abiotic fragmentation

The abiotic factors-forest type relationship was preliminary analyzed. A forest type could be related to one or more abiotic factors where this presence depends on the location of specific abiotic combinations. If the combination of the abiotic factors is fragmented across the landscape then the related forest type will also be spatially fragmented.

The forest abiotic factors relationships was tested using GIS overlaying process of several layers. The total surface area of each forest type was computed with relation to

the different classes of abiotic factors. The number forest patches were also recorded with relation to the abiotic factors.

The forest abiotic relationship is better studied on continuous or less fragmented spatial representation of the forests. Less fragmented forest patches were needed which forced us to use the 1965 forest map, considering that older forest spatial information might be less fragmented. It is known that forest types in Lebanon are spatially dependant on elevation (vegetation-altitude zones) and on the geological formations (Abi Saleh *et al.*, 1996). However, this research uses a very detailed forest map of Lebanon from the past for the first time. Since we are the first that produced the digital version of the 1965 forest map; we used GIS techniques to investigate the forest distribution with regard to elevation and other abiotic factors. The change of the forest patch size was also investigated with relation to elevation (Table 14).

Table 14. Abiotic factors divisions to explore their possible relation to forests.

| Component of analysis | Major elements | Major classes | Tools of analysis |
|-----------------------|------------------|--|-------------------|
| Topography | Vegetation zones | Mediterranean | Topographic maps |
| | | Mediterranean presteppe | |
| | Slope gradient | Very steep slopes (>60%) | |
| | | Steep slopes (30-60%) | |
| | | Moderate slopes (15-30%) | |
| | | Gentle slopes (0-15%) | |
| | | North (337.5-22.5°) | |
| | Slope aspect | Northeast (22.5-67.5°) | |
| | | East (67.5-112.5°) | |
| | | Southeast (112.5-157.5°) | |
| | | South (157.5-202.5°) | |
| | | Southwest (202.5-247.5°) | |
| | | West (247.5-292.5°) | |
| | | Norwest (292.5-337.5°) | |
| | Roughness | Number of each slope gradient and aspect at the forest patches | |
| Geology | Rock type | Limestone and dolomite | Geologic maps |
| | | Marl, clay and shale | |
| | | Sandstone and clastics | |

Urban effect on forest fragmentation

The distance between forest and urban settlements were calculated in Lebanon. The number and area of the urban sprawl was recorded. Forest patches were extracted from the forest map of 1965, while urban patches were digitized from the topographic map of 1962.

Urban settlements were also investigated with regard to forest spatial locations. The degree of urban expansions was computed with regard to forest spatial locations. It is obvious that urban expansion was grown chaotically across Lebanon. In order to quantify how this growth was developed, we conducted new thinking of spatial change investigations. Forests of 1965 were used as fixed forest locations. However, urban areas were changed and expanded toward the forest areas. It was possible to know the degree of urban expansion with regard to forest patches through using one forest GIS layer of 1965 and two different urban settlements layers of 1965 and 1998.

The mean nearest neighbor index (MNN) was computed on two different layers as follows: the first layer consist of the forest patches and urban settlements of 1965. The second layer is the same forest patches of 1965 with urban expansion of 1998. The change in the index was considering the degree of threat that urban expansion is exerting on forests.

Forest change related to patch size and shape or strip like patch shape (Direction and orientation of the forest patches)

Forest changes in 1998 were investigated for their possible relation to 1965 patch shape and size. The changes of the forest patches were investigated according to patch level. The percent area of forests in each 1965 forest patch was investigated in 1998, i.e., the remaining forest area was examined. The loss of forest area was checked if might depend on original patch size and shape.

Other related measurements were developed to which forest changes might also depend. We calculated what we called patch strip-shape. This measurement examines how the patch is elongated in shape or stretched in one direction. The usually used landscape metric, i.e., shape index determines the degree of complexity of a patch. This will not explain if the patch has a strip-like shape or not. We considered that a strip-like forest patch is more susceptible to human interference than large and round-like patches. As there is difference between wide and narrow corridors (Forman and Godron, 1986;

Vogt *et al.*, 2007), there should also be a difference between patches of strip and normal shape.

We, therefore, developed an index to examine the patch shape if it was strip-like or not. The index is based on measuring widest zone of the patch and compares it to patch perimeter.

$$Psls = \frac{Lw}{P} \times 2$$

where *Psls* is the degree of relative patch strip-like shape; *Lw* is the largest distance (m) within a patch (connects the two poles of the patch); and *P* is the patch perimeter (m). The index is large when patches are completely strip-like shape, and it approaches zero on round-large patches.

At the same time, drawing the *Lw* has helped to investigate the orientation of the forest patches for each zone of Lebanon. Forests of Lebanon are almost mountainous in habitat. The orientation of the forest patch was converted into linear shape following the widest zone of the patch (*Lw*). A line connecting the most distinct poles of the patch replaced each forest patch. Orientation of the lines will respond to the geomorphological formation of the mountains in Lebanon.

Transition matrix and changes over the landscapes

Transition matrix determines the landscape pattern changes. Forest patches of 1965 were checked for their changes in 1998, utilizing the 1965 forest map and the 1998 landcover map of 1998. The changes were studies on forests of both sides of Lebanon, the coastal and inner land. Transition proportion were computed which equals the changed area of one patch type (forest class) from 1965 to 1998, divided by the area of the patch type in 1965 (Kebrom and Hedlund, 2000).

2.2. Forest analysis at the study area

Similar analyses, which were performed on overall forest area of Lebanon, were also accomplished for the study area but they were more exhaustive and with important additions.

The spatial fragmentation analysis was accomplished for four different periods 1965-1972, 1972-1989, 1989-1998 and 1998-2003. Landscape indices were computed for each period and changes were investigated. Landcover data for the investigated periods were first prepared from classifying satellite images.

The data used in this part of the research was the maps: (i) forest map of 1965 and landcover map of 1998 and (ii) the satellite images of Landsat for the years 1972 and 1989, Spot 5 for 2003 and of IKONOS for 2005. The 1998 spatial data was extracted from the existed landcover map.

Forests of 1965 at the study area

The necessity to ameliorate the 1965 forest map was first proven during field investigations for this research in 2003. Both topographic and forest maps of the study area were brought onsite. Forest patch spatial delineations showed critical differences between both maps. This main uncertainty during field investigations started while comparing a forest patch next to Silaata village. This site was covered with forests during field examination in 2003. In addition, between 1968 and 1974, Dr. Abi Saleh phytosociologically studied this same site and classified the forests under the vegetation series of carob (*Ceratonia siliqua* L.) forests (Abi Saleh, 1978). The topographic map designated the site as woods. However, the 1965 forest map does not display any forests at this same site. We realized that the 1965 forest map could have missing forest patches, which are critical in forest spatial research like ours.

Initially, both forest and topographic maps were visually inspected for their differentiations in patch delineation. The number of disparities was spotted and recorded with regard to each forest map-sheet. Both maps, forest of 1965 and topographic, (produced in the same period) have same spatial scale of 1/50,000. They were produced using same black and white aerial photos of the 1962 aerial mission around Lebanon. In

other words, these maps were descended from the same source of data and printed on the same spatial scale. Therefore, they are directly comparable under GIS environment but they require preprocessing steps as mentioned above (Figure 23).

The topographic map delineates woods (*bois*) and shrubs (*broussailles*) instead of the forest legends that are shown on the 1965 forest map (Figure 26). Every patch on the forest map was compared to the topographic map and the final delineation was considered based on logical decisions.

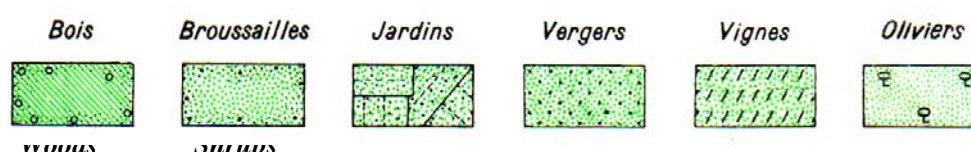


Figure 26. Legends for the vegetations on the topographic map, demonstrating woods and shrubs.

Aerial photos of the 1962 mission were also used to correct the forest map of 1965 (see the part Materials above for forest map of 1965 origin). This was only in doubtful locations. Landsat MSS of 1972 was also used to support further comparison. Since small forest patches will not appear on the Landsat image with low spatial resolution (such as MSS), we also used Spot 5 satellite image of 2003. The spatial scale used in this research is 1/50,000 following the base map (i.e. the forest map of 1965). The smallest forest patch area in this research might reach 2,500 m², which is smaller than the Landsat MSS pixel size (80x80 m). Only for such situation the Spot 5 of 2003 was used that has 10x10 m pixel size. The comparison between forest and topographic map was performed using GIS layers overlaying and visual inspection of satellite images.

Organizing and synchronizing the landcover map of 1998

The importance of the 1998 landcover map is being digitally available as a GIS layer. However, it could not be used for direct comparison with the 1965 forest map. The landcover map was produced by different authors though different perspectives and different spatial scale.

The forest legends of both maps were first assembled in a list where similar forest types were aligned together with their cover density (Table 15). Each forest type on the 1965 forest map was aligned to its similar one on the 1998 landcover map. However, care should be taken because forest types are easily aligned but the coverage density might not exactly align between both maps. The 1998 landcover map, presumably, does not use parallel rates or diagnostic measures as the 1965 forest map when coverage density of the forests assigned. It was not clear what the exact ranges or methods used to compute the different coverage density of the forest patches. Therefore, it will be more appropriate to generalize the forest legend under the main forest type, losing or eliminating the coverage density (Table 16).

Table 15. Aligning legends for forest types of two maps 1965 and 1998.

| 1965 forest map | | 1998 landcover map (forests) | |
|----------------------------------|----------|---|----------|
| Forest type | Coverage | Forest type | Coverage |
| <i>Pinus pinea</i> | >40% | <i>Pinus pinea</i> | Dense |
| <i>Pinus Brutia</i> | >40% | <i>Pinus Brutia</i> | Dense |
| <i>Pinus pinea, Pinus Brutia</i> | 10-40% | <i>Pinus spp.</i> | Clear |
| <i>Cedrus libani</i> | >40% | <i>Cedrus libani</i> | Dense |
| <i>Cedrus libani</i> | 10-40% | <i>Cedrus spp</i> | Clear |
| <i>Abies cilicica</i> | * | <i>Abies cilicica</i> | Dense |
| <i>Abies cilicica</i> | 10-40% | <i>Abies spp.</i> | Clear |
| Juniper | 10-30 | <i>Juniperus spp.</i> | Clear |
| Juniper | >30% | <i>Juniperus spp.</i> | * |
| Cypress | * | <i>Cupressus sempervirens</i> | Dense |
| Cypress | * | <i>Cupressus spp</i> | Clear |
| Oak standard, Oak coppice | >30% | Mixed woodland | Dense |
| Oak standard, Oak coppice | 10-30% | <i>Quercus spp.</i> , Other type of broad leaves, Mixed wood land | Clear |

*Not listed on the original map.

Table 16. Forest legend generalization on both maps 1965 and 1998.

| 1965 forest map | | 1998 landcover map (forests) | | Legend harmonization |
|----------------------------------|----------|---|----------|-----------------------|
| Forest type | Coverage | Forest type | Coverage | |
| <i>Pinus pinea</i> | >40% | <i>Pinus pinea</i> | Dense | <i>Pinus spp.</i> |
| <i>Pinus Brutia</i> | >40% | <i>Pinus Brutia</i> | Dense | |
| <i>Pinus pinea, Pinus Brutia</i> | 10-40% | <i>Pinus spp.</i> | Clear | |
| <i>Cedrus libani</i> | >40% | <i>Cedrus libani</i> | Dense | <i>Cedrus libani</i> |
| <i>Cedrus libani</i> | 10-40% | <i>Cedrus spp</i> | Clear | |
| <i>Abies cilicica</i> | * | <i>Abies cilicica</i> | Dense | <i>Abies cilicica</i> |
| <i>Abies cilicica</i> | 10-40% | <i>Abies spp.</i> | Clear | |
| Juniper | 10-30 | <i>Juniperus spp.</i> | Clear | <i>Juniperus spp.</i> |
| Juniper | >30% | <i>Juniperus spp.</i> | * | |
| Cypress | * | <i>Cupressus sempervirens</i> | Dense | <i>Cupressus spp</i> |
| Cypress | * | <i>Cupressus spp</i> | Clear | |
| Oak standard, Oak coppice | >30% | Mixed woodland | Dense | Oaks |
| Oak standard, Oak coppice | 10-30% | <i>Quercus spp.</i> , Other type of broad leaves, Mixed wood land | Clear | |
| | | | | |

*Not listed on the original map.

Derivation of landcover map of the study area on successional periods (Satellite images classifications)

Landcover maps are the basis for landscape structural analysis. Since the launch of satellites, remote sensing provided data essential for the production of landcover maps that are used to detect, e.g., forest loss (e.g. Lopez Garcia and Caselles, 1991; Lioubimtseva, 2003). Recently, landcover maps are used as important data to investigate spatial patterns of forest loss through the application of landscape indices (Hansen *et al.*, 2001; Ward *et al.*, 2007; Boentje and Blinnikov, 2007).

Digital image classification uses the DN-value/pixel of one or more spectral bands of an image by clustering similar DN values pixels into separate classes. This classification type is called spectral pattern recognition. The objective of this classification is to assign all pixels in the image to particular classes or themes of landcover (forest, urban, etc). The classified image comprises mosaic of pixels, each of which belongs to a particular theme, producing a thematic map of the studied area.

We used satellite images of different periods to establish series of landcover maps for the study area. The obtained landcover maps are for the years 1972, 1989 and 2003. As a result, detailed forest analysis was performed. The first year 1972 was based on Landsat MSS images (Multi Spectral Scanner) with a resample resolution of 80 m/pixel. The other image series were based on the sensor Landsat TM and Spot 5.

Our field investigation has started in 2003 at the date of retrieving Spot 5 satellite images. Field knowledge for the study area was also accumulated in 2003. The direct relation of the Spot 5 scenes with field observation (image acquisition and field observation are performed in the same year, i.e., 2003) has helped to ameliorate the classification decisions and to get familiar with various landcover types. The classification of the Spot 5 satellite images were first performed, as it helps in the classification of other images.

Satellite images classification were processed using ERDAS Imagine 8.7 software. The classifications of the Spot 5 satellite images have passed into several steps. First, we performed an unsupervised classification that was developed by carrying out ISODATA processing to identify spectrally distinct areas (Tou and Gonzalez, 1974). Second, the unsupervised image were brought onsite together with other ancillary data, which they are the forest map of 1965, landcover map of 1998 and the topographic maps of the study

area. GPS (Global Positioning System) was used in the field to record observations geometrically and follow the information on different maps (Figure 27).

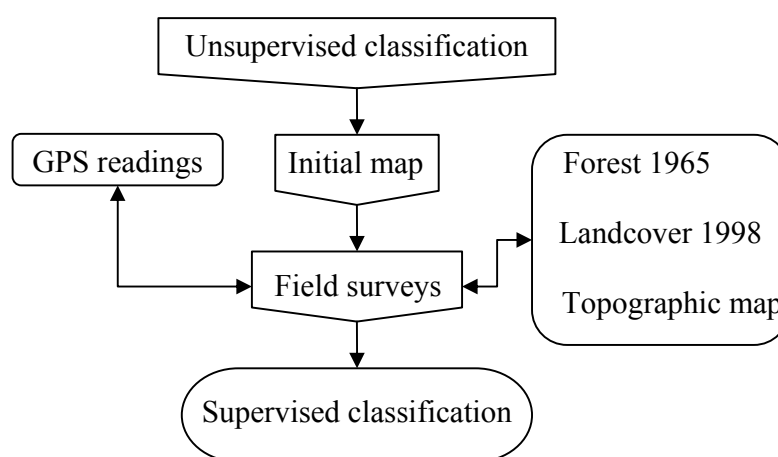


Figure 27. Classification of the satellite images, the followed steps.

First, we used the forest spatial information of the 1965 map to better direct our field trips. Each forest patch of this map was visited. The 1998 landcover map helped to track forest area increase (new forests compared to 1965) or decrease. The unsupervised classified Spot image enabled us to easily separate oak forests into different forest cover density.

The unsupervised classification assigned 14 classes which they include six forest types among them (oak at the coast, oak at the inland, junipers, pines, cedars and cypress), urban (settlements), quarries, field crops, fruit trees, bare rocks, bare soils, grasslands and water bodies. However, oaks of the inland were not perfectly detected. Nevertheless, juniper forests was badly detected or not detected at all in many places where confusions with bare lands have happened. In such areas, field investigations were added and increased.

Training sites were recorded on a region-wise (minimum 10 to 15 pixels in more or less square like form), discriminating different landcover types. They were selected based on data found on the unsupervised classified image and on direct observation onsite. Training sites (parametric signatures), which reached 423 for the fourteen classes intended (chosen in the unsupervised image), were introduced into a supervised classification process (using ERDAS Imagine 8.7 software), i.e., to train a statistically

based classifier based on maximum likelihood model. For many applications, Maximum Likelihood has proven to be effective with marginal difference to other methods (Benediktsson *et al.*, 1990). Maximum likelihood algorithm requires that histograms of the bands have normal distribution for each band. The decision rule is based on the probability that a pixel belongs to a particular class.

Superimposing the forest, topographic and landcover maps onto satellite images of older periods assisted in performing visual interpretation and defining further training sites. Visually 116 training sites were also defined. In addition, use was made for the empirical observation that some forest types are associated with certain altitudinal ranges (Abi Saleh *et al.*, 1996; Hoersch *et al.*, 2002). Among the ground landcover data that were gathered in 2003, 159 points were considered to represent no change locations (urban settlements, old forest growth, conservation areas, etc.). These 159 ground data points helped to determine further training sites for completing the classification of the 1972 MSS and 1989 Landsat TM images. This procedure is useful, especially when working with earlier (belong to the past) satellite images (Cayuela *et al.*, 2006). The 159 no change areas were used in supervised classification algorithm in order to classify the other satellite images. As a result, landcover maps of different periods for the study area were obtained.

Field and ground verification points (control points) were collected onsite but in different places of the training sites (see the paragraph of *accuracy assessment* below).

Accuracy assessment

Accuracy assessment involves identifying a set of sample locations (field and ground verification points or control points) that are visited in the field. Control points are compared according to their exact location with the classified images. In other words, the land cover found in the field is compared to that which was mapped in the image for the same location by means of error or confusion matrices.

Field surveys in 2003 helped to identify 260 control points. Validation of the Spot 5 landcover map was achieved using 174 independent ground control points. The TM and MSS landcover maps were verified based on an interpretation of 86 ground control points that had not changed over time. The 86 points were used to construct the confusion

matrix of the classified images of Landsat, while the other 174 points assisted in constructing the related 2003 confusion matrix. Similar to training sites, control points were converted into areas (polygons of 15 to 20 pixels) which allowed the computation of user's accuracy, producer's accuracy and overall accuracy in the confusion matrices. The control polygons (based on the control points) were selected during field observations (on the unsupervised images) and then compared to pixels visually on screen.

Transition matrix of forest cover

The landcover changes throughout the different periods were investigated. Inside forest patches of 1965, landcover was followed for different periods according the classified images (above). Each forest type was analyzed for the main landcover class that has replaced the forests. This step was performed similarly as for the part of landcover change overall Lebanon, using superimposition of maps in GIS facilities.

3. Structural changes

3.1. Spatial configuration changes of the forest patches

As mentioned above, landscape spatial metrics or indices were calculated on patch level, i.e., each forest patch was assigned by its size, shape complexity and edge length. Changes of these indices were investigated at each studied period of the research. A new approach of analysis was established to clarify the degree of forest patch changes throughout the landscape using patch-based metrics. The shift of the metrics from a linear regression correlation between each patch is the degree of total landscape indices shift from previous time period. For example, shape index on patch level of two consecutive years if it has plotted on a regression curve the difference between both years is the degree in which the curve slope angle deviates from perfect correlation.

This will also answer if the spatial characteristics are related with time periods. In other words, the spatial characteristics change of a forest patch in date 1 might or might not allow us to estimate future spatial changes of the same patch.

Another question arose here; do the spatial characteristics of a forest patch in date 1 answers forest qualitative data of date 2? This is still one of the focuses of ecology today.

In this context, we also searched that if forest cover density in date 2 is related to forest spatial characteristics of date 1. Does the shape complexity or the size of a forest patch in date 1 reflect future forest cover density?

3.2. Regeneration, Patch based analysis

Inside/outside patch comparison – (1965-2003)

Landscape indices will give important indication of change in landscape spatial pattern. However, important forest spatial information might stay unknown or unclear if these indices were only used especially in Mediterranean forests. Mediterranean forests might change quite rapidly (in short period), such as oak forests or human rehabilitation of other forest types (Salleo *et al.*, 2002; Moreira *et al.*, 2007).

Landscape indices discard or will not detect the forest changes because of regeneration. Forest regenerations (or new growth) were considered as the appearance of forests to the outside of the original patches in 1965. Therefore, this type of change will not appear by using only the landscape indices. We, however, searched each 100 m outside the original (old or date 1) forest edges for the new forest regrowth (in date 2). This has provided in date 2 the area of each forest type and the distances from the forest edges to date 1.

Although forest of date 1 has changed and probably lost some area a new regrowth might appear and on different distances from forest edge. This determines in details the dynamics of the forests.

3.3. Hemerobiotic state of the investigated forests

As mentioned in literature part of this research, hemeroby is a measure of human influence on ecosystems. It is the distance between the present and the pristine, undisturbed indigenous vegetation. In this regard, we used different criteria for dividing forests into different hemerobiotic stages or levels. In order to assess the hemerobiotic

state of forests, we used the density of roads at each forest patch to be the targeted indicator. The road density was computed as follows:

$$RD = \frac{R_l}{P_p}$$

where RD is the road density at the forest patch; R_l is the road length in meters that passes across the forest patch; P_p is the patch perimeter in meters. The ratio RD compares the road length to patch perimeter length. RD reaches 1 or more when the road has same perimeter length or even taller. RD reaches 0 in forest patches where roads do not cross.

The other criterion was the composition of the forest patch. A patch with lower canopy closure (density of forest cover) is considered distinct from reaching naturalness compared to dense forest patch. In addition, the description of the forest trees was also counted as another criterion. Oak forests, for example, were divided between coppices and standard trees like shape on the 1965 forest map. Coppice trees or shrubs are the form of trees that undergone major human interference.

Previous studies have searched for natural or anthropogenic edges as neighboring forests. Certainly linear features like roads were investigated for their effect on the species level biodiversity with a forest.

Mediterranean forests have the problem of overgrazing and also of heavy hunting. Shepherds and hunters pass through the forests and clump the soil. In Lebanon, man sometimes passes on foot through the forest to make a faster cut across the forest. Therefore, linear or curvilinear features appeared within the forest patches.

Linear tree like features are also another characteristic of the forest around Lebanon. This tree shape (linear tree like shape) is the result of human interference within the structure of the forest.

Linear features within a forest patch were detected using high spatial resolution satellite images (IKONOS) of 2005. We attempted searching for linear features within forest patches such as trails.

3.4. NDVI in forest investigations

NDVI to examine forest changes quality and quantity

The Normalized Difference Vegetation Index (NDVI) calculates the vegetation density or greenness of an area of land. This index is computed through the formula:

$$NDVI = \frac{NIR - R}{NIR + R}$$

where *NIR* is the near infrared band and *R* is the red band.

The NDVI is nonlinear function, which varies between -1 and +1. NDVI values vary with absorption of red light by plant chlorophyll and the reflection of infrared radiation by water-filled leaf cells. It is correlated with Intercepted Photosynthesis Active Radiation (IPAR). NDVI can be used as an indicator of relative biomass and greenness (Boone *et al.*, 2000). If sufficient ground data is available, the NDVI can be used to calculate and predict primary production, dominant species, and grazing impact and stocking rates (Ricotta *et al.*, 1999). For Landsat images, NDVI is calculated from bands number 4 (NIR) and 3 (Red). However, Spot 5 multispectral images have the second band as the Red and the third one as NIR band.

NDVI was used to answer largely the forest spatial configuration might change from one year to another. NDVI differencing was performed between the satellite images of the investigated period. After using the threshold of $2 \pm \text{STD}$, we were able to detect fire and quarries at the study area on extent of forest patches. This also provided major differences within the forest patches in the studied successive periods (Jomaa and Bou Kheir, 2003). Forest region changes are only performed for oak forests on both parts of the study area: coastal and inner part.

3.5. Physiographic analysis of the landscape

a. Topographic complexity of a forest patch

The present research study area encompasses more than 90% mountainous terrain with rugged topography, which plays predominant role in shaping the landscape. Using the landscape indices alone will not reflect the enormous topographic effect on ecological processes and functional relationships. We, therefore, have introduced simple descriptive measurements for topography reflecting its accentuated effect on the forest patches.

Contour lines of 10 m equidistance were used to build a Triangulated Irregular Network (TIN) for the study area under GIS environment of ArcMAP 9.2 software. TIN is a data structure used to model elevation of an area as a connected network of triangles. The geographic space (the area) is partitioned into contiguous, non-overlapping triangles called faces.

The number of faces were counted within each forest patches. The topographical complexity of a forest patch is the relative number of the faces. The relative number of topographic faces (RTF) of a forest patch is computed as the total number of faces/total patch area in hectares. The obtained value increases as the topographic complexity within a forest patch increases (highly rugged geomorphology). It should be noted that the area of each face (triangle) depends on the homogeneous topography, which could be represented by the triangle. Therefore, very rugged area will have higher number of triangles (faces) with small areas (Figure 28).

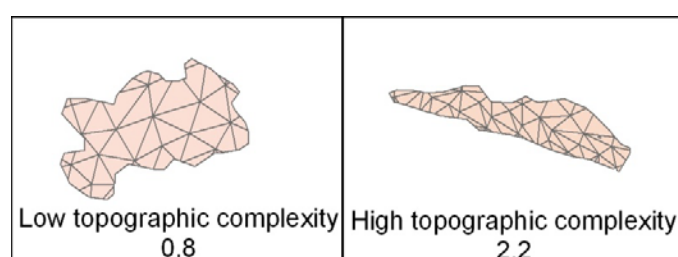


Figure 28. An example of patch degree of complexity using our developed index.

b. Connectivity of forest patches

Dorner *et al.* (2002) presented three approaches of integrated topography into landscape analysis and landscape metric calculations. These are: (1) adjustment of areas and distance calculations to avoid systematic biases in landscape statistics; (2) design of indices that capture characteristics of vegetation pattern in relation to topography; and (3)

use of statistical models to describe broad-scale relationships between topographic characteristics and vegetation patterns.

Consequently, new indices will continue to derive which make ecologists face a long list of descriptive metrics (Gustafson, 1998). New emerged topographically related landscape metrics are therefore under prediction, since without topographical analysis and relation to metrics in certain areas will induce misleading final interpretation. Dorner *et al.* (2002) urge for further topographical insertions within metric computations and/or development of novel approaches for assessing the topographic influence on landscape pattern and processes.

We tested the mean nearest neighborhood index (MNN) as the most affected by topographic complexity of an area. We added “quality of the nearest neighbor distance” instead of computed the non-Euclidean distance (topographic distance) of MNN between patches. The MNN distance will not clearly describe the connectivity, because it only computes the projected distance between forest patches. Ecologically, topographic characteristic of such distance will be more informative of real connectivity. We developed an index based on the mean nearest neighbor index but it uses the topographic features of the studied area. We simply counted the number of slope aspect and gradient within the MNN distance, which indicated the quality of the distance on forest type level.

The new index describes how the topographical characteristics within the nearest neighbor distance are. The number of faces within this specific distance provides how the connectivity is hard or soft between the forest patches. This analysis was conducted for both slope aspect and frequency. The slope aspect was divided into eight parts, i.e. North (N), Noreast (NE), East (E), South East (SE), South (S), South West (SW), West (W) and Norwest (NW) on tin format grid file using ArcGIS 9.2. The values of each pixel indicated the angle in degrees for each slope aspect. Flat slopes were given the value -1, indicated no direction (Figure 29). The slope gradient was measured in degrees on the Digital Terrain Model. The slope angle will be the tangent *rise* over the *run*.

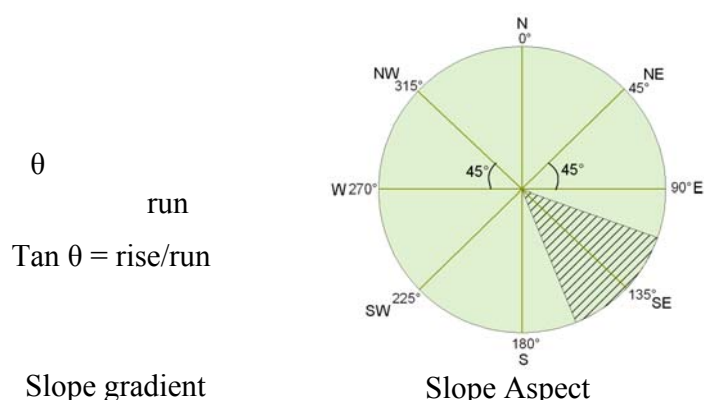


Figure 29. Slope gradient calculation and slope aspect divisions.

3.6. Forest delineation and its importance for landscape analysis

During our investigation of forest changes, juniper forests showed important changes in their surface coverage. Large area of junipers appeared to be lost. In reality, juniper forests were subjected to cuttings. However, the way in which juniper forests were represented on a map had influenced this large result of changes in the surface area. Authors of the 1965 forest map circulated the juniper trees to include them in one patch although they might not fit in one homogeneous patch on the 1/50,000 spatial scale.

The actual (on ground) distance variability of this tree causes the cartographer to largely generalize forest patches. However, this generalization has affected the spatial configuration analysis. If cartographer only draws a line around such forests, it will intensely give error to the full figure of the exact coverage of such forest. We realized that the 1965 cartographer had increased the total forest coverage of Lebanon by 3 or 4% at most through misleading circulation of junipers. We consequently believe that cartographers had and still have problems in representing this forest type.

Since then, homogeneous patches are the basic units in forest ecological investigations and landscape analysis. The distance between trees is an essential biodiversity feature of a forest patch. Therefore, we digitized the area that surrounding junipers, using new and special method. We draw a circle with 20 m of a diameter. This circle (we called locker circle) was moved between the junipers trees on an IKONOS image (Figure 30). Each two or more trees that have their edge (tangent canopy) touch

the circumference or the trees are included within the digitized forest patch. These trees were joined and included in one homogenous patch. Trees will be joined into one forest patch moving the circle from one-tree edge to another tree edge in a chain like form. The patch will end at the point that the trees get far outside the circumference. This method is actually fixing the spatial scale from one hand and creates homogeneous units that might be easily compared and monitored.

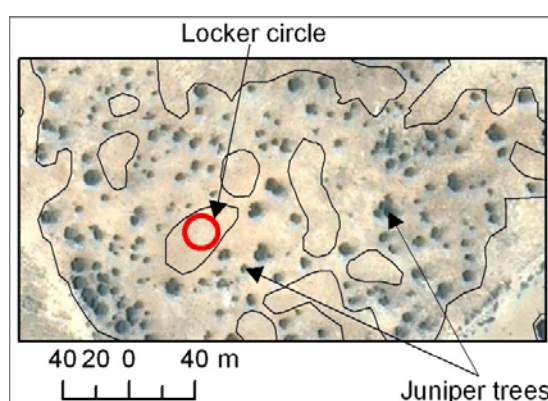


Figure 30. Setting the scale and drawing details between trees.

The method will allow measuring exactly the surface coverage of the juniper trees without any exaggeration. Furthermore, monitoring of changes will be based on ecological quantification fixed manner. Monitoring became possible with this logical rule of patch delineation.

Materials and methods fast summary

The materials used for the entire research and their detailed characteristics are listed in tabular form (Table 17). The purpose of each material that was used for the study is briefly mentioned.

Table 17. Fast summary of materials used and their purposes.

| Data used | | date | Scale/resolution | Legend/type | Utilization in the thesis |
|---|-----------------|-------|------------------|--------------------------|--|
| Maps | Topographic map | 1962* | 1/20,000 | Woods, shrubs | <ul style="list-style-type: none"> - Field investigation: guiding for forest patches found on the map as woods and shrubs. - Correcting the spatial patterns of the 1965 forest map. - Extracting urban settlements of 1962. - Extracting roads of 1962. - Contour lines of 10 m for orthorectification. - Contour lines to analyze the topographic complexity of the study area and forest patches. - Possible correlation of forest spatial distribution with slope aspect and gradients. |
| | Topographic map | 1962* | 1/50,000 | Woods ,shrubs | <ul style="list-style-type: none"> - Field investigation. - Correcting spatial patterns of the 1965 forest map. |
| | Forest map | 1965* | 1/50,000 | See table 8 and 16 below | <ul style="list-style-type: none"> - Extracting forest-attributing data. - Extracting spatial forest data for all Lebanon. - Forest fragmentation in Lebanon and the study area. - Comparing different parts of Lebanon. - Investigating forest changes to other landcover type. |
| | Landcover map | 1998 | 1/20,000 | See table 9 and 15 below | <ul style="list-style-type: none"> - Forest spatial pattern comparison. - Urban change approaching forests. - Forest fragmentation in Lebanon and the study area. - Comparing different parts of Lebanon. - Investigating forest changes to other landcover type. |
| | Geological map | 1943 | 1/50,000 | See annex I (geology) | <ul style="list-style-type: none"> - Possible correlation with forest spatial distribution. |
| | | | | | |
| Satellite images | Landsat MSS | 1972 | 80 x 80 m | Multispectral | <ul style="list-style-type: none"> - Extracting landcover map. - Detecting misrepresentation of juniper forests. |
| | Landsat TM | 1989 | 30 x 30 m | Multispectral | <ul style="list-style-type: none"> - -Preparing landcover map. |
| | Spot 5 | 2003 | 10 x 10 m | Multispectral | <ul style="list-style-type: none"> - Preparing landcover map. - - Urban change approaching forests. - NDVI changes, especially for oak forests (characteristic of regeneration and location). - Forest regeneration and regrowth analysis. |
| | Ikonos | 2005 | 80 x 80 cm | RGB-pan-sharpen | <ul style="list-style-type: none"> - Extracting dents of a forest patch. - Analysis for the Hemerobiotic state of forest patch. - Offering a solution for better spatial representation of juniper forests. |
| * All three maps derived from aerial mission (aerial photos) of the year 1962 over Lebanon. | | | | | |

Part III.



Chapter 5

Fifty years of forest cover changes

Our main objectives are understanding fragmentation and evolution of forests in Lebanon, using GIS, remote sensing and existing maps of landcover and forests. Two different axes of investigations were performed in order to accomplish this research. The first one was accomplished overall forests in the country while the other axe of research had entered in a detailed forest change inventory over a chosen study area in Lebanon.

1. A global view of the forests in Lebanon was first required especially to what is related to landscape spatial configurations. Lebanon's two main climatic regions are the coastal part (occidental) and inner lands (oriental). Previous studies found differences in species compositions and forest types between forests of both parts; where landscape pattern was only investigated from the point of view total area of forests. Therefore, we constructed a concept for landscape spatial analysis for the forests in Lebanon that will change future perspectives of new studies and their way of thinking about forests. We were also able to benefit from the existing forest and landcover maps available for the whole country in a unique manner.

Landscape structural configuration analysis was first used to investigate the differentiation between occidental and oriental Lebanon. Existed landcover and forest maps were used to investigate landcover types that replaced previously forested areas.

Forest relations to abiotic factors were investigated in GIS environment. If a forest habitat related to one or more abiotic factors, then the spatial configuration of this forest will be greatly affected by the spatial distribution of such abiotic factors. We examined, therefore, the spatial configuration of the abiotic factor that a forest depends upon. If these factors were spatially fragmented, then the forest would follow a similar trend, i.e., it will be highly fragmented as well.

Another technique was employed using a landscape index and existing spatial information of urban expansion. The degree of how urban settlements approached forests

was introduced which help building comprehensive view of how they affected forest fragmentation.

The changes of the spatial characteristics of forests were used to investigate the applicability of landscape indices over Lebanon as part of the Mediterranean environment. It is the investigation of forest loss relation to previous (past) landscape pattern configurations. Innovation of new indices was accomplished that led to discover a new characteristic related to the forests of Lebanon.

2. Further forest analysis was carried out on a chosen study area of Lebanon. First, we investigated the accuracy of the forest spatial distribution on the existing. This step was only accomplished for the study area but it is actually required for the whole country (for the limited time of this research this study concentrates only on a specific area of Lebanon). Successive forest change analysis using available satellite images was performed. A new concept helped to investigate regenerated forests and spotting degraded (forest loss) areas. An original approach was created to properly delineate the spatial distribution of juniper forests. If cartographers of forests in Lebanon remain to follow the same spatial representation method of junipers forests, monitoring of such forests will stay impractical and leads to improper results. Nevertheless, the necessity for developing a hemerobiotic scale (index) for forest in Lebanon was demonstrated. This index should follow landscape spatial analysis especially in Mediterranean forests where human interference is high. The difference of occidental and oriental forests was performed using NDVI, which was also used to investigate forest changes. This step was important for forest fragmentation analysis because some forest types change in a very short period from non-forest to forested area or vice versa. Another novel analysis was performed (all related to forest fragmentation) that is topographic analysis of the forests. Topographic complexities of the forests were considered a sign of different fragmentation phenomenon.

1. Forest cover changes overall the Lebanese territory

1.1. Changes of forest cover between coastal and inner parts of Lebanon

In 1965, total forest area occupied 13.8% of the Lebanese territory (Table 18). Oak coppices cover the largest area among all forest types. Forests of Lebanon consisted of 56.5% oaks; junipers were the second important forest type that forms about 23% of the forest area; cedars were only about 2% of the total forest area; pines had almost similar forest area to cedars in 1965.

Changes in forest cover were analyzed using the area statistics derived from forest map of 1965 and landcover map of 1998. The estimated cover of native forests decreased from 144,253 ha in 1965 to 136,420 ha in 1998. In other words, only 5.4% of the forest area has been lost during the entire period 1965-1998. During the whole investigated period, the annual deforestation rate was 237 ha year⁻¹. In the landcover map of 1998, oak forests were not separated between oak coppices and standards; as well the pines were joined under one forest type, i.e., pine forests. There was also 15,396 ha (11% from the forest area in 1998) of forest area classified as mixed forests of which 70% are included in the coastal region.

Table 18. Forest types of Lebanon and their total area in 1965.

| Forest types | | Cedars | Oak coppices | Oak standard | Junipers | Stone pine | Calabrian pine | Cypress | Fir | total |
|--------------|---------|--------|--------------|--------------|----------|------------|----------------|---------|--------|----------|
| Area (ha) | Lebanon | 3068.6 | 78336.3 | 3084.1 | 33244.9 | 11280.8 | 13062.2 | 347.9 | 1828.5 | 144253.3 |
| % area | 1965 | 2.1 | 54.3 | 2.1 | 23.0 | 7.8 | 9.1 | 0.2 | 1.3 | 13.8* |
| Area (ha) | Lebanon | 1136.2 | | 83660.5 | 11925.5 | | 20345.6 | 204.8 | 1604.6 | 118877.2 |
| % area | 1998 | 0.8 | | 61.3 | 8.7 | | 15.0 | 0.2 | 1.2 | 13** |
| Area (ha) | Coast | 2612.1 | 46146.2 | 2241.1 | 6193.4 | 11237.9 | 11611.8 | 321.4 | 1828.5 | 82192.4 |
| % area | 1965 | 3.2 | 56.1 | 2.7 | 7.5 | 13.6 | 14.1 | 0.4 | 2.2 | 7.9 |
| Area (ha) | Coast | 1136.1 | | 66323.5 | 3802.2 | | 17975.9 | 204.8 | 1489.7 | 90932.2 |
| % area | 1998 | 1.2 | | 72.9 | 4.2 | | 19.7 | 0.2 | 1.6 | 8.7 |
| Area (ha) | Inland | 456.5 | 32190.1 | 843.0 | 27051.5 | 42.9 | 1450.4 | 26.5 | 0 | 62060.9 |
| % area | 1965 | 0.7 | 51.8 | 1.3 | 43.5 | 0.0 | 2.3 | 0.0 | 0 | 6 |
| Area (ha) | Inland | 0.1 | | 17337 | 8123.3 | | 2369.7 | 0 | 114.9 | 27945 |
| % area | 1998 | 0 | | 62 | 29 | | 8.5 | 0 | 0.4 | 4.3 |

*percent forest area from the Lebanese territory. **This percentage includes all forest area shown on the landcover map, i.e., the 136420.4 ha (the forests shown in the table plus the area of the mixed forest type found on the 1998 map); 13% forest area from the Lebanese territory in 1998.

In 1965, the forest area was distributed more equally between the coast and inlands (7.9% at the coastal part and 6% to the inland), which actually it was 57% at the coast and 43% toward inlands. Thirty-three years later, this forest distribution has broken to

more unequal distribution, which showed to be 76% in the coastal part. Inland forest at the has shown large area decrease (about 3400 ha) between 1965 and 1998 (Figure 31).

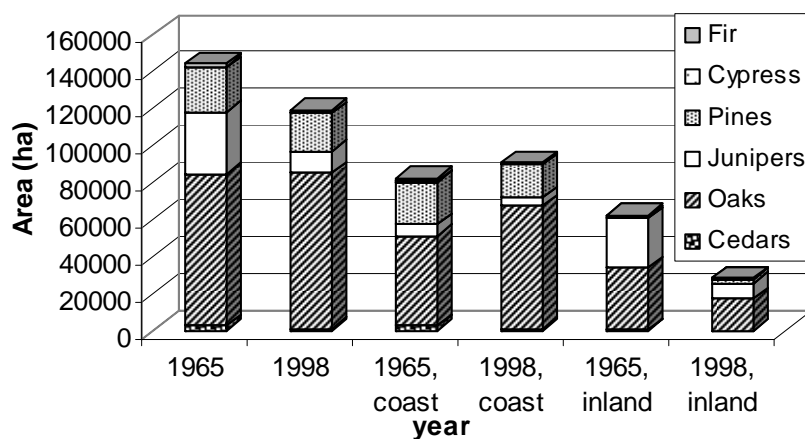


Figure 31. Forest types distribution along the coastal and inner part of Lebanon, comparing 1965 to 1998.

Forest compositions on both sides of Lebanon did not change. Oaks are distributed on both sides of the country. Cedars, pines, cypress and fir are forests of the coast. Almost 80% of juniper forests are situated within the inland part of the country. Oaks forests showed surface area increase (about 17000 ha) toward the coast between 1965 and 1998. All other forest types have decreased in their cover on both sides of the country.

1.2. Landscape spatial configuration and fragmentation analysis

- Variation of forest patch size and number

One of the basic symptoms of fragmentation is the increase in number of smaller patches of forests (Figure 32). In Lebanon, considerable changes were found in the forest patch size distribution among the selected ranges between 1965 and 1998. By 1998, 41% of the forest area was concentrated in isolated patches of less than 50 ha in size. This value was 8% in 1965. Small sized patches (less than 50 ha) constituted 43% of total forest patches in 1965; this number increased to reach about 92% in 1998.

The total number of patches had increased by approximately seven times between 1965 and 1998, with decrease of total forest area and increase in small sized patches. The annual increase in forest fragment number (forest patch number) was approximately 177 which corresponded to 17%/year from the original forest fragment number in 1965. In 1998, the mean patch size reached about 20 ha with STD (Standard deviation) of 61 ha; while it was 143 ha with STD of 360 ha in 1965.

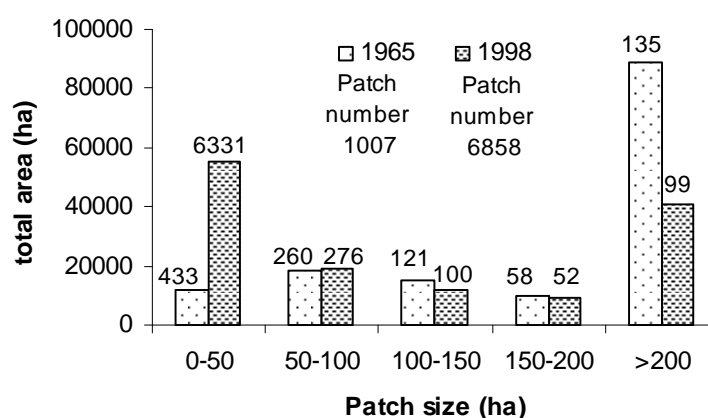


Figure 32. Variation of forest patch size in Lebanon; the numbers on top of each bar are patch numbers for each patch size range.

The forest changes were also investigated comparing the Mediterranean ensemble to Mediterranean presteppe vegetation zones in Lebanon. This will explain which area of

Lebanon undergone most forest changes, e.g., forest fragments number. This step was, further, analyzed for changes on forest type level or class level.

Forest area, in the coastal part of Lebanon (Mediterranean vegetation zone), increased from 82192 ha to 90929 ha in the period 1965-1998 (Figure 32). This 10% increase of forest area was based on various changes with regard to forest types. Only oak forests have shown an increase in its surface area; but this low increase in area was followed by augmenting largely the number of forest fragments by about 14%. Although all other forest types undergone area decrease, their fragment number increased. The forest mean patch size was 107 ha (STD 284 ha) in 1965 and decrease to reach 22 ha (STD 56 ha) in 1998.

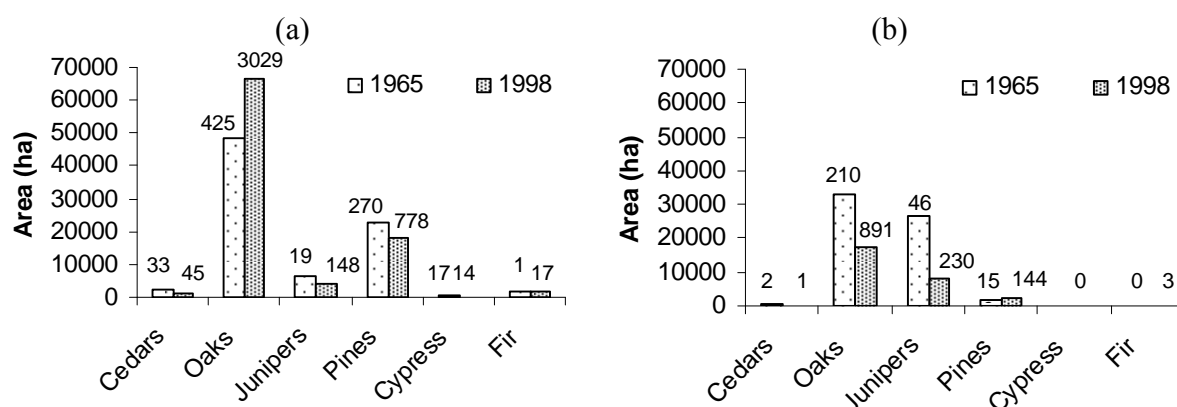


Figure 33. Forest type changes between 1965 and 1998 in coastal part (a) and inland (b).

Forest area, at the inner lands of Lebanon (Mediterranean presteppe vegetation zone), had decreased by approximately 50% (Figure 31). Oak and juniper forests are the main forest types of inner Lebanon. They faced important fragmentation phenomenon where oak and juniper forest area decrease by 50% was accompanied by increase of 23% and 20% in their patch number, respectively. Mean patch size decreased from 225 ha (STD 217 ha) in 1965 to 22 ha (STD 67 ha) in 1998.

Although the 1998 map was resampled to match the spatial scale of the 1965 forest map, a special comparison of the original (intact) maps was performed. Forest patches of both maps overlapped and the remained forest area (patches) inside the original patch of 1965 was computed. This operation was performed to analyze patch fragmentation according to how much forests remained inside. For example, fragmented forest patch of

1965 showed decrease by more than 60% of area and also showed important number of forest patches on the inside (inside the 1965 forest patch). This fact was proved and investigated in previous study (Jomaa *et al.*, 2007).

- *Patterns of fragmentation*

The above modifications of the landscape were characterized by the presence of more patch edges, which increased from 7122 km to 20,429 km in the period 1965-1998. The edge length was significantly different between the investigated years ($\chi^2 = -0.019$; $p = 0.547$). This increase of forest fragment edges was accompanied with a decrease in total forest area revealing an increase in irregularity.

Other spatial configuration changes had also occurred (Table 19). The total mean patch size (MPS) decreased from 558 ha to 62 ha on landscape level. This 90% decrease of patch size was based on different changes among forest types and class level. Juniper forests showed the highest decrease in patch size that reached 96%. This forest appears to be the most affected by loss in area and fragmentation. The landscape has undergone forest area decrease, increase in forest fragment number and decrease in fragment size. In addition, the Shannon diversity and Shannon evenness indices increased (SHDI from 1.8 to 1.89 and SHI from 0.68 to 0.82), suggesting the fragmentation of the landscape during the investigated period. The Mean Shape Index (MSI) was larger than one for all the forest type explaining that forest patches are having less compact form or shape. Area Weighted Mean Size Index (AWMSI) demonstrated that larger patches are even less compacted. However, the Area Weighted Mean Patch Fractal Dimension showed that patches have simple shapes with less complexity. The Mean Nearest Neighbor (MNN-Euclidean) distance shows 55% decrease which is the result of large increase in forest fragment number and it has no relation to better assembling between forest patches of same types. This decrease in MNN is related to the fragmentation of largest forest patches. The overall interspersion and juxtaposition index (IJI) increased that indicates desegregation trends.

Table 19. Changes in landscape pattern indices for forest types in 1965-1998*.

| | MPS (ha) | | MSI | | AWMSI | | AWMPFD | | MNN (m) | | IJI | | LPI | |
|----------|--------------|-------------|------|------|-------|------|--------|------|---------|--------|------|------|------|------|
| cedars | 146.2 (215)* | 54.2 (68) | 1.79 | 1.91 | 2.4 | 2.94 | 1.1 | 1.14 | 1858.3 | 829.2 | 53.3 | 27.0 | 0.6 | 0.18 |
| Oaks | 111.6 (527) | 37.2 (196) | 1.85 | 1.93 | 7.7 | 6.64 | 1.1 | 1.21 | 3873.9 | 177.2 | 34.4 | 47.2 | 1.5 | 3.48 |
| Junipers | 1108.6 (380) | 35.0 (136) | 2.22 | 2.00 | 5.6 | 6.88 | 1.1 | 1.23 | 1532.6 | 152.6 | 55.1 | 61.3 | 14.8 | 1.27 |
| Pines | 139.8 (336) | 33.7 (135) | 3.95 | 1.94 | 8.1 | 5.46 | 1.1 | 1.20 | 1188.9 | 402.3 | 44.6 | 55.5 | 1.2 | 1.66 |
| Cypress | 19.26 (14) | 13.8 (15) | 1.53 | 1.82 | 1.6 | 2.24 | 1.0 | 1.12 | 5750.4 | 4771.0 | 61.9 | 24.7 | 0.0 | 0.04 |
| Fir | 1822.7 (0) | 200.1 (497) | 3.26 | 2.73 | 3.2 | 10.2 | 1.1 | 1.28 | 0.0 | 105.5 | 0.0 | 70.8 | 1.2 | 1.13 |

*Numbers in brackets is STD; Un-shaded columns are for 1965 and shaded ones are for 1998.

In 1965, coastal part Edge Density was larger (59 m/ha) than the inner lands (35m/ha), suggesting higher shape complexity of the patches (Table 20). The mean nearest neighbor (MNN) was more than double toward the inlands with regard to the coast (2414 m inlands and 1003 m at the coast). In 1998, Edge Density had increased almost the double for the coast and the triple for inlands. Total Edge (TE) has also shown an increase of approximately 46% for both parts of the country. Mean Patch Size has been the most affected by large decrease of about 82% at the coast and 90% inlands. The Mean Nearest Neighbor decreased and Mean Proximity increased indicating a decrease in the distance between forest fragments. This distance decrease is the result of breaking up of large forest patches to smaller ones and it is not related to better forest spatial configuration changes. The coastal part demonstrated changes to an uneven distribution of patches; while inland demonstrated better interspersed and aggregation of patches. This, as mentioned before, is related to more fragmentation of large patches at the inlands.

Table 20. Landscape pattern changes at the two parts of Lebanon in 1965-1998.

| | MPS (ha) | TE (m) | ED (m/ha) | MNN (m) | MPI | IJI | LPI | SHEI |
|------------|-----------|----------|-----------|---------|-----|-----|------|------|
| Coastfr65* | 156 (451) | 4806900 | 59 | 1003 | 285 | 60 | 7.4 | 0.0 |
| Innerfr65 | 315 (906) | 1633900 | 35 | 2414 | 496 | 37 | 40.0 | 0.5 |
| Coastfr98 | 27 (149) | 10873900 | 104 | 745 | 643 | 47 | 4.5 | 0.6 |
| Innerfr98 | 28 (134) | 3514500 | 108 | 411 | 362 | 62 | 9.9 | 0.7 |

*Coastal forest of 1965. Numbers in brackets are the STD.

Forests either in 1965 or in 1998 were largely clustered into spatial groups, i.e., they were less dispersed (significance level = 0.01). In Ecological terms, forest fragments are spatially dependent and they are found in different clusters around the landscape. It seems like if somebody had placed them as clusters throughout the landscape.

1.3. Landscape succession

To describe the spatial development of landscape patterns and highlights the dominant dynamic events during the study period, forest degradation was quantified. Regeneration was not taken in account. About 9% of the 1965 oak forests area was converted into grasslands by 1998 (Table 21). Another 4% were replaced by cultivations. Urban and bare rocks have covered 2.5% of the oak forests. Cedars were mainly replaced by grasslands to about 4%. Although junipers have demonstrated large area decrease (above), it was modestly replaced by grasslands with only 1.5%. Pine forests were equally replaced by agriculture and urban to approximately 4%.

Table 21. Forest change between 1965 and 1998.

| Lebanon 1998 landcover to the inside of 1965 forest patches | | | | | | | |
|---|---------------|---------------------|--------------------|--------------------|---------------|---------------|-----------------------------|
| 1965 forests | Urban (ha) | Agriculture (ha) | Grasslands (ha) | Bare rocks (ha) | Water (ha) | total (ha) | total forest loss (%) |
| Cedars | 0.1 | 11.7 | 150.9 | 6.0 | 0.0 | 168.7 | 5 |
| Oaks | 1040.4 | 3329.0 | 7711.3 | 1205.3 | 4.1 | 13290.1 | 16 |
| Junipers | 21.5 | 861.4 | 5131.4 | 2504.9 | 0.0 | 8519.2 | 25 |
| Pines | 961.8 | 1080.0 | 685.4 | 33.0 | 4.0 | 2764.2 | 11 |
| Cypress | 7.6 | 112.9 | 38.6 | 11.7 | 0.0 | 57.9 | 16 |
| Fir | 0.0 | 128.2 | 60.6 | 1.7 | 0.0 | 190.5 | 10 |

Table 21. continue.

| Costal area 1998 landcover to the inside of 1965 forest patches | | | | | | | |
|---|---------------|---------------------|--------------------|--------------------|---------------|---------------|-----------------------------|
| 1965 forests | Urban (ha) | Agriculture (ha) | Grasslands (ha) | Bare rocks (ha) | Water (ha) | total (ha) | total forest loss (%) |
| Cedars | 0.0 | 0.0 | 7.6 | 0.0 | 0.0 | 7.6 | 0.3 |
| Oaks | 714.0 | 2196.0 | 1555.0 | 19.3 | 3.0 | 4487.3 | 9.3 |
| Junipers | 0.0 | 24.9 | 1041.0 | 113.0 | 0.0 | 1178.9 | 19.0 |
| Pines | 924.0 | 957.0 | 648.0 | 27.0 | 4.0 | 2560 | 11.2 |
| Cypress | 7.6 | 112.9 | 38.0 | 11.7 | 0.0 | 170.2 | 53.0 |
| Fir | 0.0 | 128.2 | 60.6 | 1.7 | 0.0 | 190.5 | 10.4 |

Table 21. continue.

| Inner land 1998 landcover to the inside of 1965 forest patches | | | | | | | |
|--|---------------|---------------------|--------------------|--------------------|---------------|---------------|-----------------------------|
| 1965 forests | Urban (ha) | Agriculture (ha) | Grasslands (ha) | Bare rocks (ha) | Water (ha) | total (ha) | total forest loss (%) |
| Cedars | 0.1 | 11.4 | 143.3 | 6.0 | 0.0 | 161.1 | 35.3 |
| Oaks | 326.4 | 1133.0 | 6156.3 | 1186.0 | 1.1 | 8802.8 | 26.6 |
| Junipers | 21.5 | 836.5 | 4090.4 | 2391.9 | 0.0 | 7340.3 | 27.1 |
| Pines | 37.8 | 123.0 | 37.4 | 6.0 | 0.0 | 204.2 | 13.7 |
| Cypress | 0.0 | 0.0 | 0.6 | 0.0 | 0.0 | 0.6 | 0.0 |
| Fir | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Since oaks are forests of both parts of Lebanon, we compared its landcover change between the coast and inland. Ninety percent of the urban area that replaced oaks in Lebanon was found in the coastal region. Oak forests area was changed to agriculture-use mainly along the coast.

1.4 Forest abiotics

The distribution of forests with regard to abiotic factors is stated in literatures but the results were not based on GIS. In this research (as mentioned earlier), the availability of the 1965 forest map has permitted larger survey of this relation all over Lebanon using GIS facilities.

Although forests in Lebanon are located on the mountains, forests of the coast mainly occupy the 0 to 40% slope gradient (Figure 34). Forests had about 60% of their area located on lower slope gradients. Slope gradients of 20 to 40% had the highest probability with regard to forests of pines, cedars and junipers. Oak forests were also found on relatively flat areas of 0-10% slope gradients. Oaks show similar probability between 0 to 60% slope gradients with 0.02 probability difference.

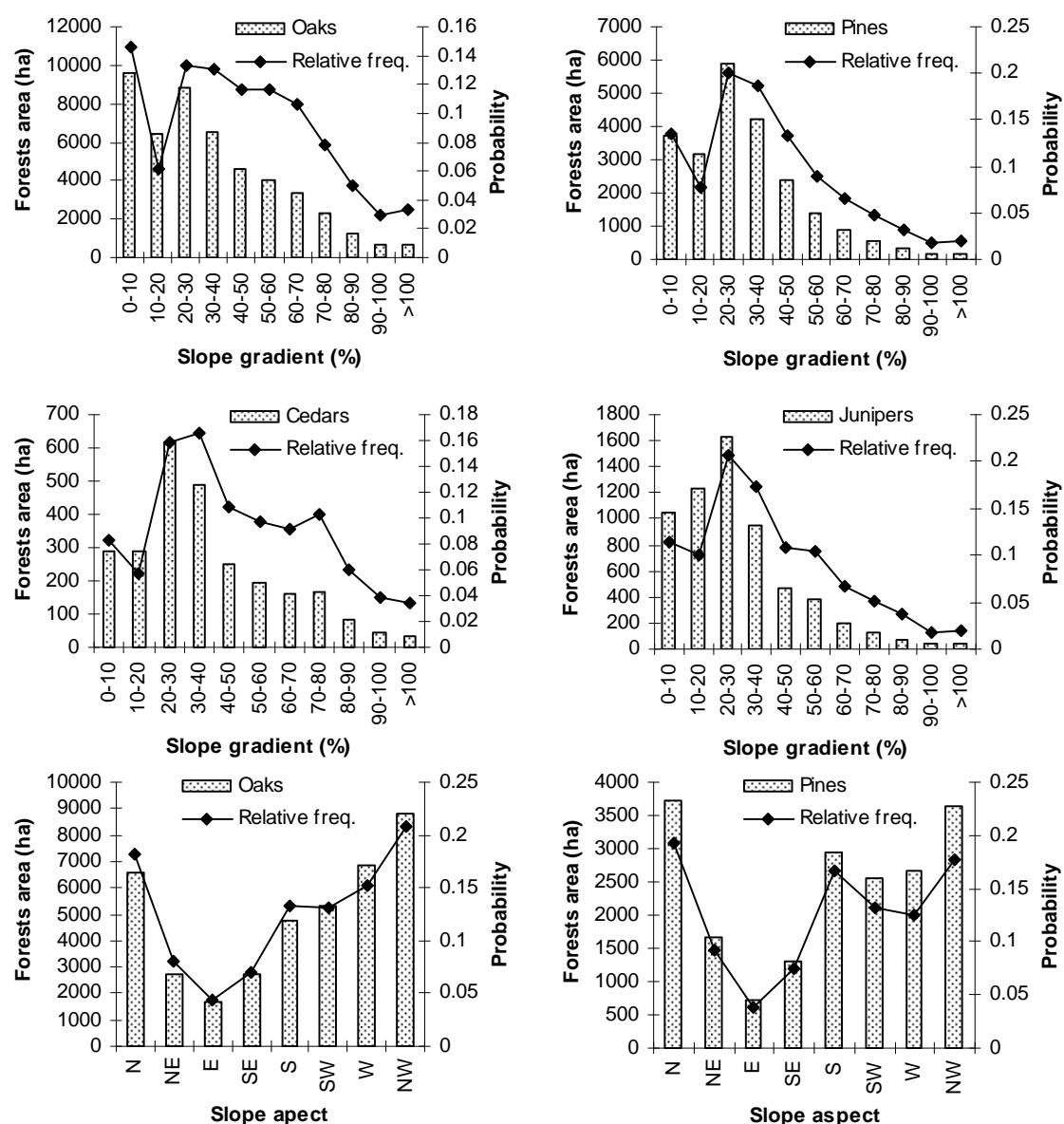


Figure 34. Different forest types presence-probability with regard to slope gradient and aspect, coastal part.

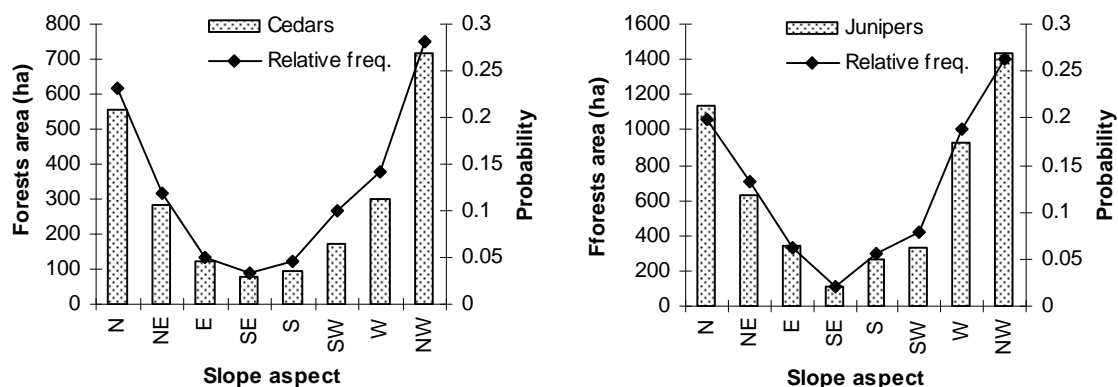


Figure 34. continue.

The presteppe vegetation zone of Lebanon (inner lands) was also investigated for forest abiotic relations. Oak forests appeared largely on wide range of slope gradients between 0 to 50% (Figure 35). Cedar forests were mainly present on slope gradients of 20-40%, which appeared to be similar to cedars forests of the coast. Junipers are found on more flat to gentle sloppy areas from 0 to 40%.

Oak and juniper forests, at the presteppe vegetation zone, are mainly found on slopes that face or oriented southeast to east (Figure 35). Cedars are mainly found on eastward slopes.

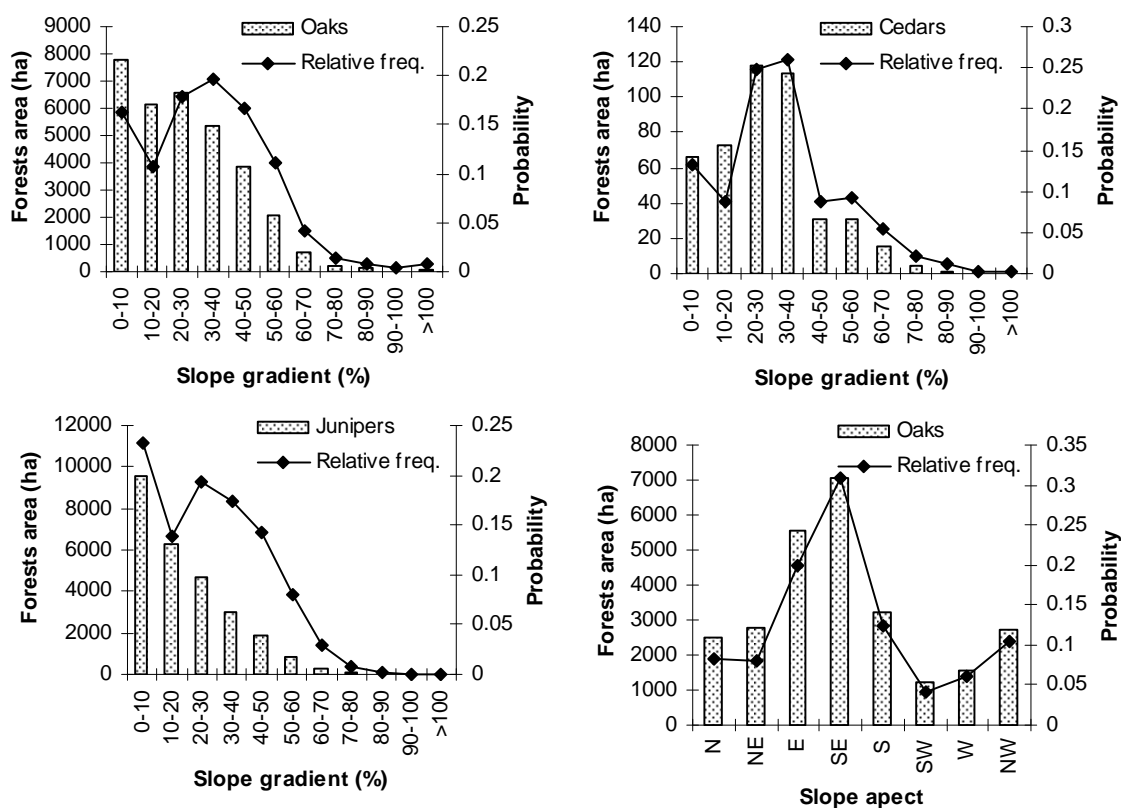


Figure 35. Forest types on slope gradients and aspect at the presteppe vegetation zone, inner lands.

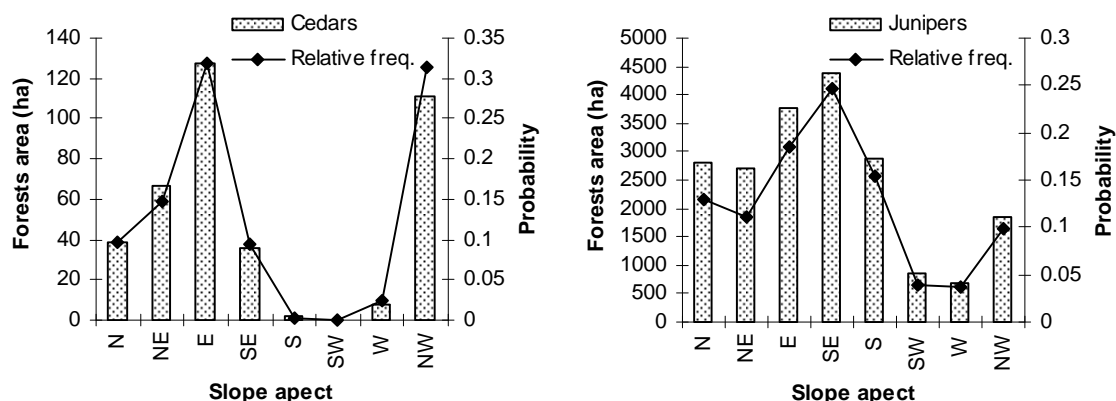


Figure 34. continue.

Distribution of the forest types was investigated with relation to the different vegetation zones around Lebanon, although it is already known (e.g. Abi Saleh, 1978; Abi Saleh *et al.*, 1996). However, the area of each forest type and probability of presence with relation to vegetation zones was geostatistically compared.

In Lebanon, Mediterranean ensemble of vegetations has five vegetation zones (coastal part of Lebanon) while Mediterranean presteppe ensemble has four vegetation zones. Oaks and pine forests are mainly distributed on the lower three vegetation zones, they are, Thermo-Mediterranean (0-500 m of elevation), Meso-Mediterranean or Eu-Mediterranean (500-1000 m) and Supra-Mediterranean (1000-1500 m) (Figure 36). Mountainous-Mediterranean (1500-2000 m) and Oro-Mediterranean (>2000 m) holds cedars and junipers forests. Although cedar forests are of similar probability being on Supra or Mountainous vegetation zones, the cedars forest area was more than double at the mountainous zone compared to the Supra one. Junipers are mainly forests of Mountainous vegetation zone.

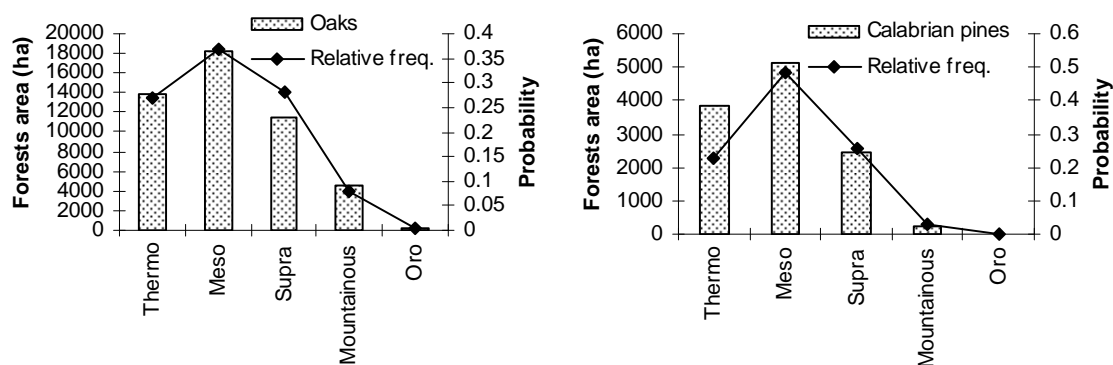


Figure 36. Forest types presence probability with relation to vegetation zones.

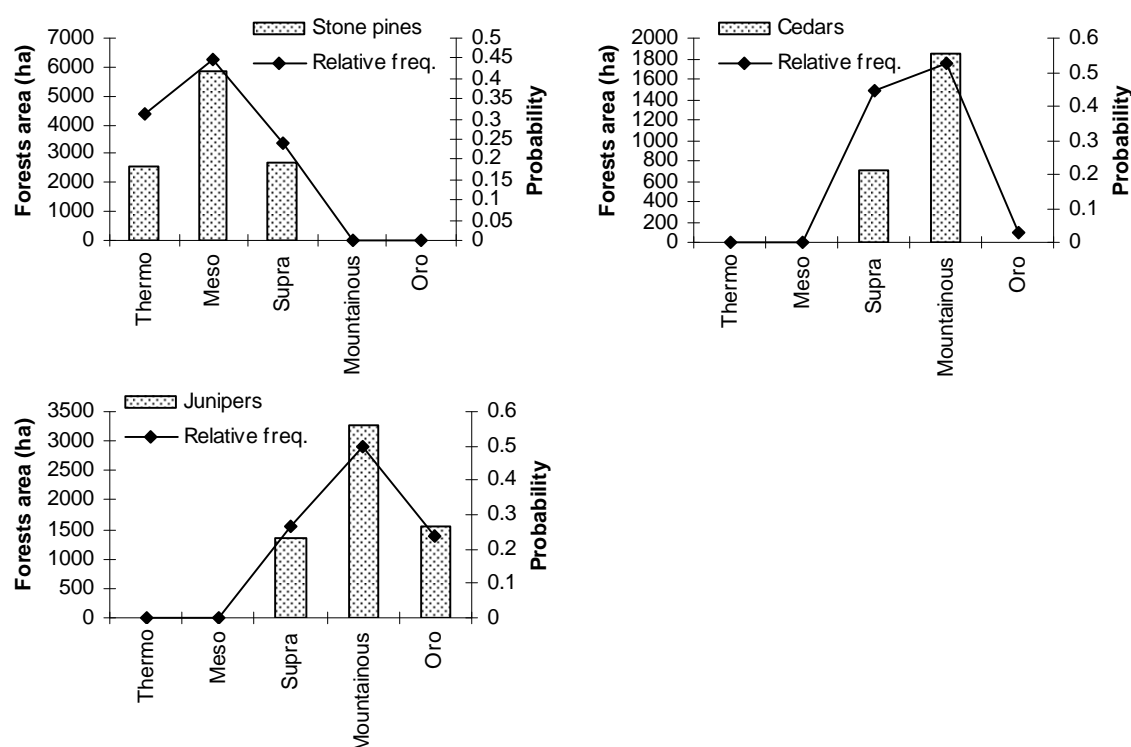


Figure 36. continue.

At the presteppe Mediterranean vegetation ensemble, oaks are the forest type of the Supra zone (Figure 37). It could also be found on both Meso and Mountainous vegetation zones. It is the forest of middle elevation on the eastern side of Mount Lebanon, i.e., Mediterranean presteppe zone. Cedar forests are found to have limited distribution on this part of Lebanon where they are present on Supra and Mountainous zones with equal probability. Although juniper forests had higher presence probability on the Supra vegetation zone, they were largely located on Mountainous and Oro vegetation zones.

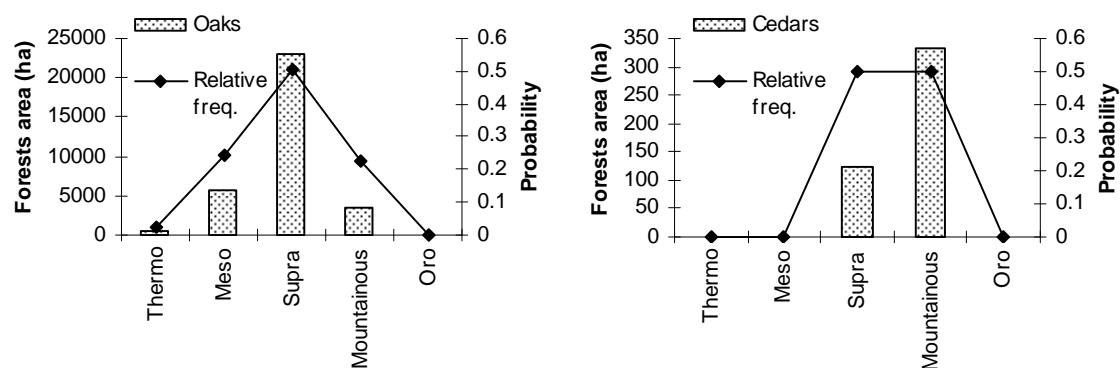


Figure 37. Forest types distribution on the different vegetation zones of the presteppe Mediterranean ensemble of Lebanon.

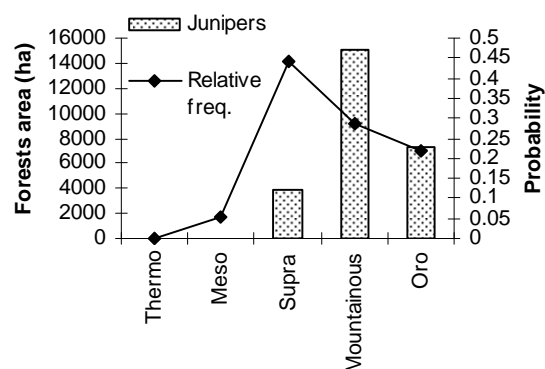


Figure 37. continue

The dominance of forests in Lebanon is related to the hard limestone and dolomite rock (carbonates) formations and they are (C4) and Jurassic (J4-7) (Figure 38). While the Stone pines is almost uniquely found on sandstone (C1) lithological formation.

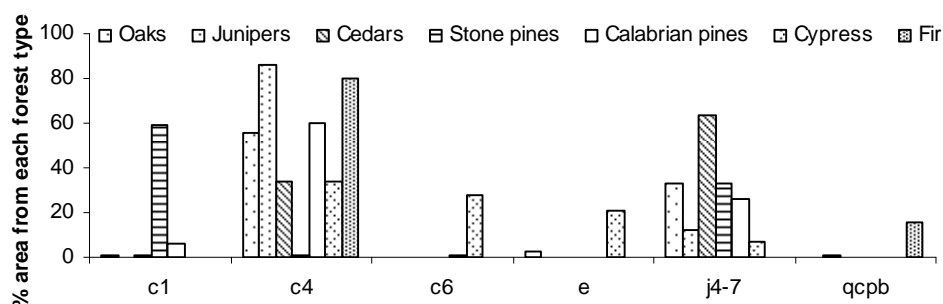


Figure 38. Forest type-geology interrelation in Lebanon.

The fact that all forests, along the coast, were mainly found on slope gradient 20-30% pushed us to investigate how fragmented this slope gradient in this area is (Figure 38). It happens that this slope gradient is highly fragmented with low mean patch size (about 2 ha) and high patch number (about 50000). Forests on this slope gradient will be fragmented accordingly. On the coastal part of Lebanon, slope gradients of 0 to 20% are relatively less fragmented compared to slope gradients from 20 to 50%. Slope gradients below 50% are largely found on the coastal part of Lebanon compared to higher ones. Therefore, it is logical to find the majority of the forests mainly distributed below 50% slope gradient. Slope gradients between 0-50% are highly fragmented which affect the possibility of having large and continuous forest patches.

Slope aspects of northern orientations (N and NW) are highly fragmented compared to other slope aspects at the coastal part of Lebanon (Figure 39). Both aspects of slope got the lowest mean patch size and the highest patch numbers. Cedar forests were found (e.g. figure 34) to be most distributed over these slope aspects which seems to stay fragmented following the spatial distribution of such abiotic factors.

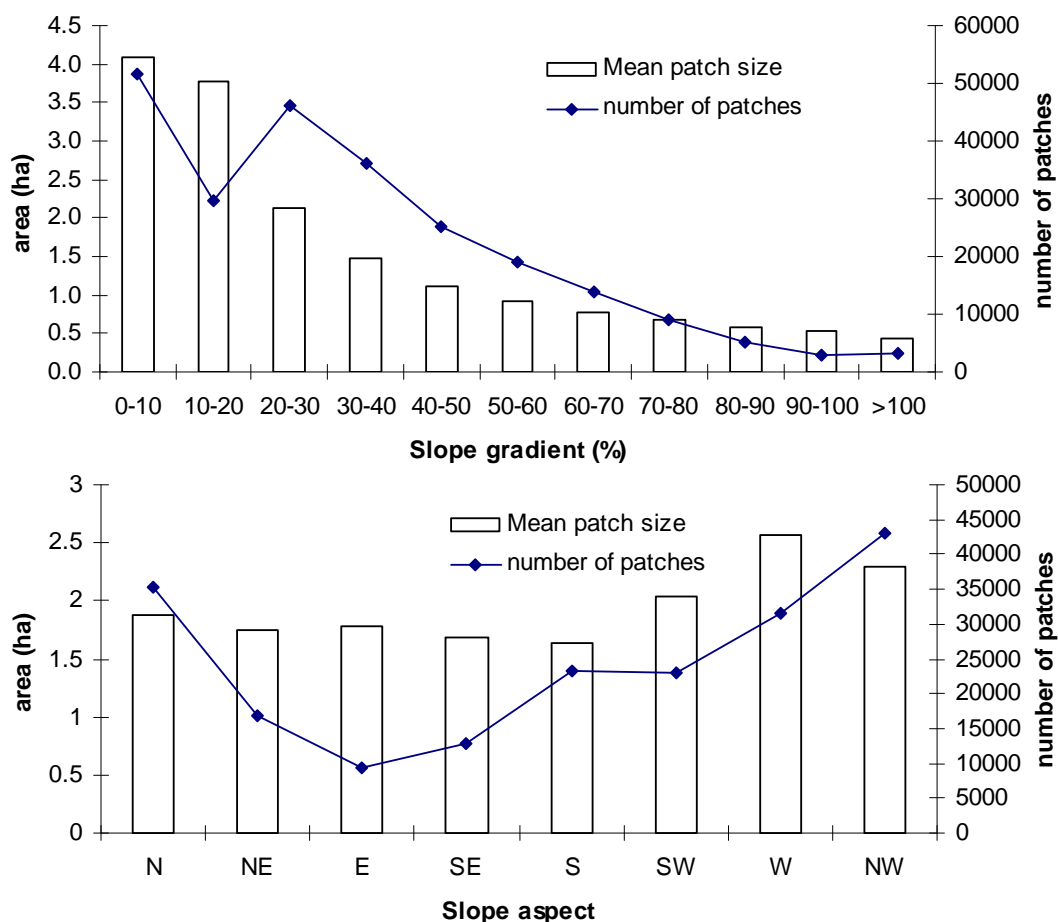


Figure 39. Slope gradients and aspects at coastal Lebanon.

1.5. Forest and urban expansion

Urban settlements, in Lebanon, have doubled between 1965 and 1998. It actually expanded from 30412 ha to 63434 ha. This large urban expansion was extended toward the forest area. The difference in Mean Nearest Neighbor (MNN) between forest patches

and urban settlements in both periods indicates the rate of urbanization on the expanse of forest areas.

By merging urban settlements of both years 1962 and 1998 on the forests of 1965, we computed the yearly urbanization rate. The MNN decreased from 608 m (214 m STD) to 260 m (185 m STD), which means urban settlements approached the forests areas of 1965 by a rate of approximately $12 \text{ m} \cdot \text{year}^{-1}$. The mean proximity index showed an increase from 1100 to 1531, displaying more clumped patches. This means that forest patches and urban expansion became more connected to each other.

1.6. Forest changes with relation to patch indices

Forests of 1965 undergone changes of different types. We searched the remaining forest area of 1998 in each of the 1965 forest patches. What we call remaining forest area in 1998, it might have not been saved throughout the entire period but it could be the result of degradation and regeneration with time. We considered a less degraded (undergone degradation through time) forest patch, the one that kept more than 60% of its forest area in 1998.

The forest patches of 1965 that kept more than 60% forest area were 32% of the total forest number. This is approximately one-third ($1/3$) of the forest patches of 1965. Another 6% (from total patch number) had between 50 to 60% forest areas remaining. About 23% of the 1965 forest patches had completely lost their forest area.

Forest loss was searched for their possible relation to original patch size or shape of 1965. Neither the size nor the shape of the 1965 forest patch had any effect or relation to forest degradation or loss that was found in 1998 (Figure 40).

The shape index measures the irregularity of form. We wanted to know if a strip like patch form has any effect on forest future change trends. Patch width, narrow or wide, might affect the trend future trend. Edge Density (ED) of a patch is related to the width where high edge density in similar sized patches is related to width characteristics of the patch. Therefore, we first checked for possible relation between ED of a patch in 1965 and forest loss of 1998.

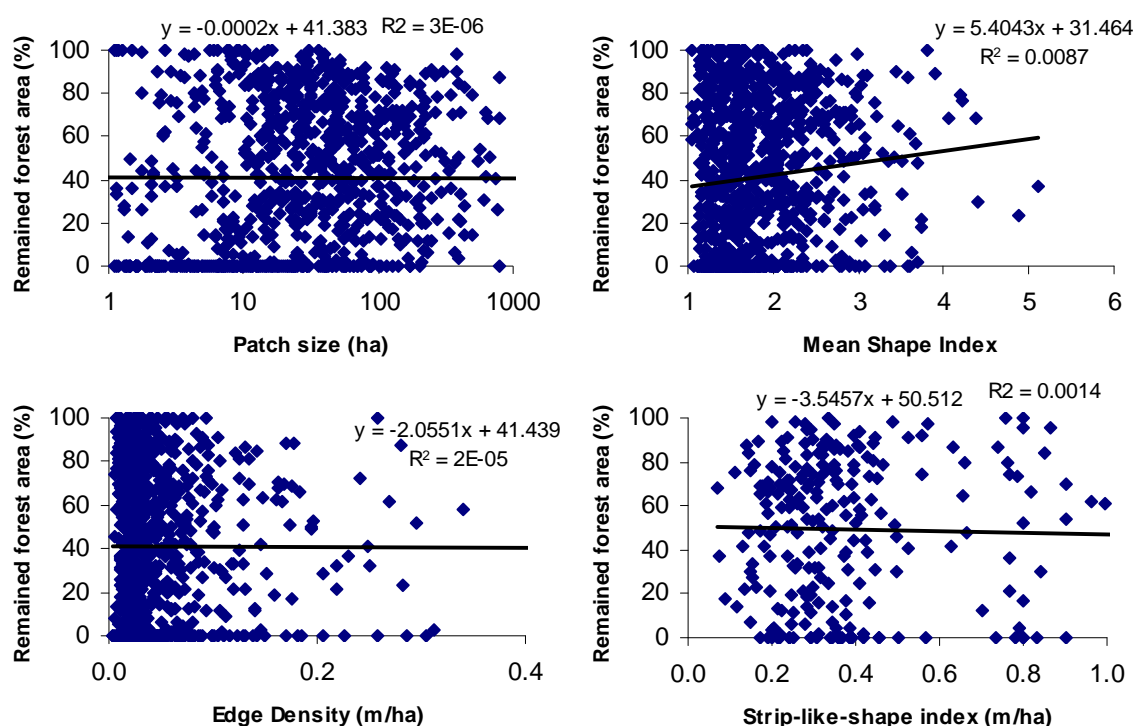


Figure 40. Forest loss between 1965 and 1998 compared to different spatial indices.

Edge Density was not related to forest loss where the regression correlation was very low (Figure 40). Therefore, we computed the degree of patch width (how wide is the patch?). We developed an index, which is the degree of patch-strip-like-shape (*PsIs*). The *PsIs* was calculated for each forest patch and checked for possible correlation to forest loss. Forest loss did not correlate with the width of the patch.

1.7. Forest patches orientations and directions

As mentioned in the methodology, the calculation of Patch strip-like shape index required drawing of the two poles of each forest patch, i.e., connecting the far ends. This line that connected both ends was considered the orientation of a forest patch. Consequently, the direction or orientation of each forest patch was extracted (Figure 41). Aspect is measured clockwise in degrees from 0, due north, to 360, again due north, coming full circle. The direction for the coastal part forests was 262° while it was 218° for inland forests. The overall forest orientation of Lebanon was 251°. The main direction

was, therefore, southwest. The 44° difference between coastal and inland forests is mainly related to main slope aspect orientation of the mountains.

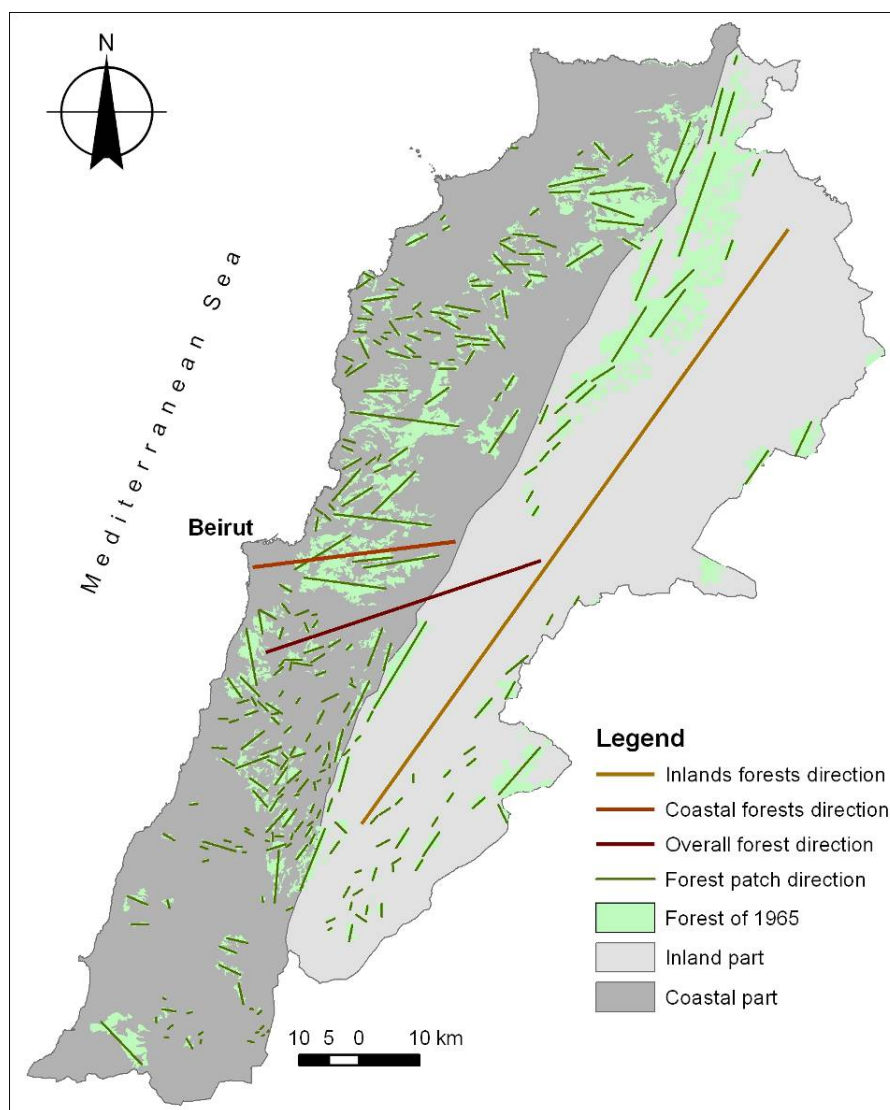


Figure 41. Forest patches direction in Lebanon.

2. Forest spatial analysis in depth

This part of the research investigates an area of 136300 ha that consist about 13% of the Lebanese territory. Detailed analysis was performed on this study area after amending the forest map of 1965. Field visits and observations were conducted around this study area helped to classify satellite image for chronicle analysis and constructing up to date landcover map.

2.1. Refurbishing of the 1965 forest map

For the purpose of this research, it was necessary to: (1) run through the doubtful differences found between the 1965 forest (patch delineations) and the topographic maps (forest delineations) and; (2) mend them before any further processes. Fragmentation analysis of the forest patches largely depends on the accuracy of the data (Riitters *et al.*, 2000). Therefore, it was compulsory to pervade the disparity involved the forest patches delineations between different data sources. As mentioned in the methodological part of this work, the patches of 1965 forest map is relatively different than others illustrated on the topographic map for the same period. A comparison between patches of both maps was performed in order to create an improved forest map of 1965, which was used and introduced for further analysis. During patch delineation comparison between forest and topographic maps, three encountered situations were tackled and solved in GIS environment accordingly (Figure 42, 43 and 44):

(1) In the first case: *a patch is missing on the 1965 forest map*, while it was shown on both topographic and satellite images. The forest patch on the topographic map was inserted into the forest map of 1965 as a new forest patch. The type of the polygon in this case was also required. Field surveys accompanied with analysis based on altitudinal vegetation zones were carried out to determine the forest type of 1965 (for vegetation zones see Abi Saleh, 1978; Abi Saleh *et al.*, 1996). Aerial photos were inspected for these specific areas because of their availability procedures. The areas where forest patches are missing on the forest map or delineated differently than the topographic map, aerial photos were stereoscopically observed. Satellite images had minimum or no effect in this case.

(2) The second case, *a forest polygon is delineated with smaller area than it is drawn on the topographic map*. The patch was extracted from the topographic map and inserted into the forest map. Satellite images together with field verifications were used to check the forest existence in the same spatial location. Aerial photos were also visually inspected for better patch delineation.

(3) The third case: *a forest patch was delineated by dashed line on the forest map* in order to represent small and un-mappable forest trees; the dashed line surrounds larger spatial area than the patches drawn on the topographic map. Therefore, the dashed line polygon was replaced with its small forest aggregated patches shown on the topographic map. The topographic map showed the exact forest locations of these small wood aggregations. The satellite images and aerial photos were checked for aggregations of forests as well.

Consequently, the original forest map of 1965 was improved with regard to the forest patch delineation for the purpose of this research. An improved forest map of 1965 at 1/50,000 scale was obtained as a base data we used for the rest of this research. The dissimilarities between the original and mended 1965 forest maps were investigated for their number of patches and the total forest surface area.

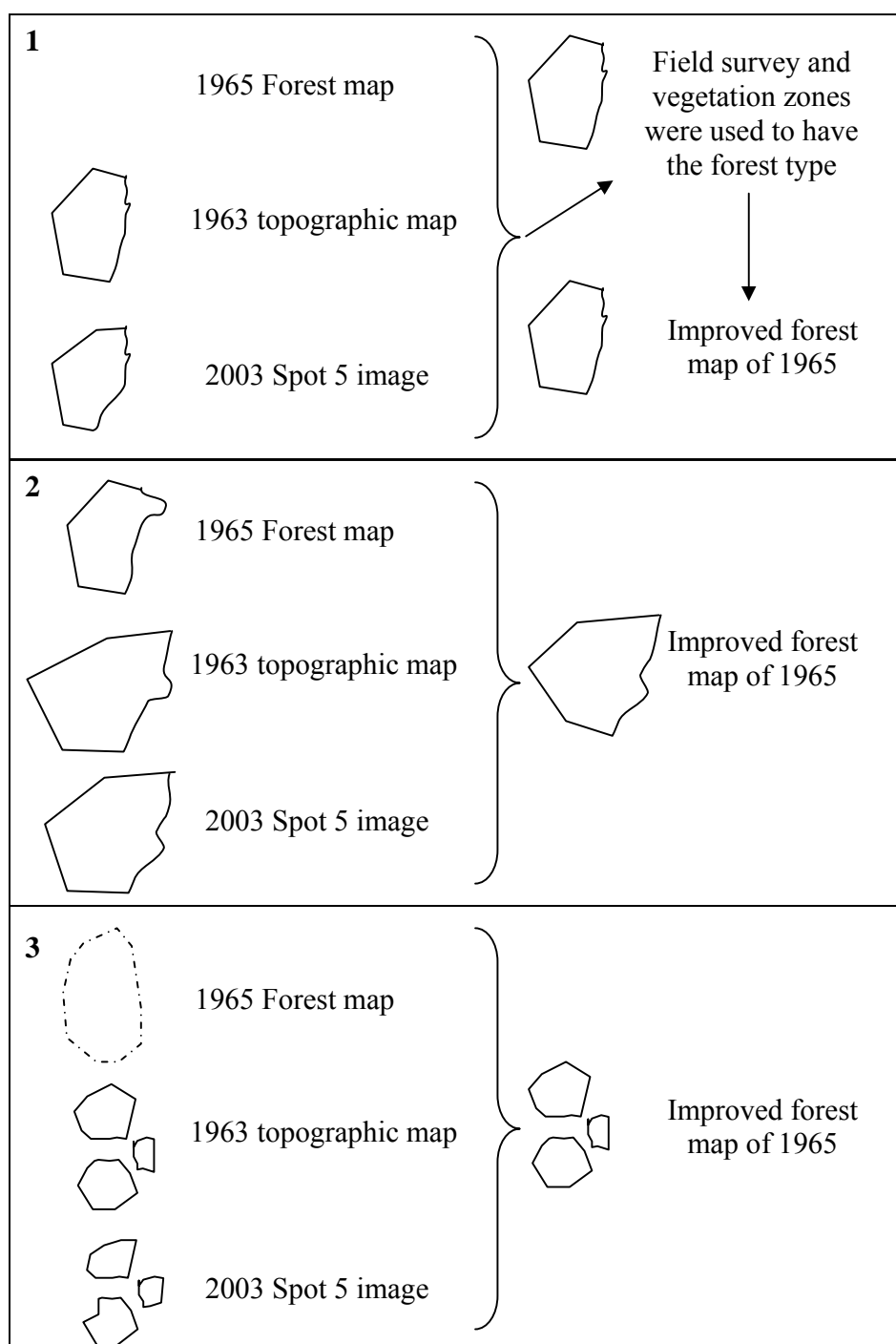
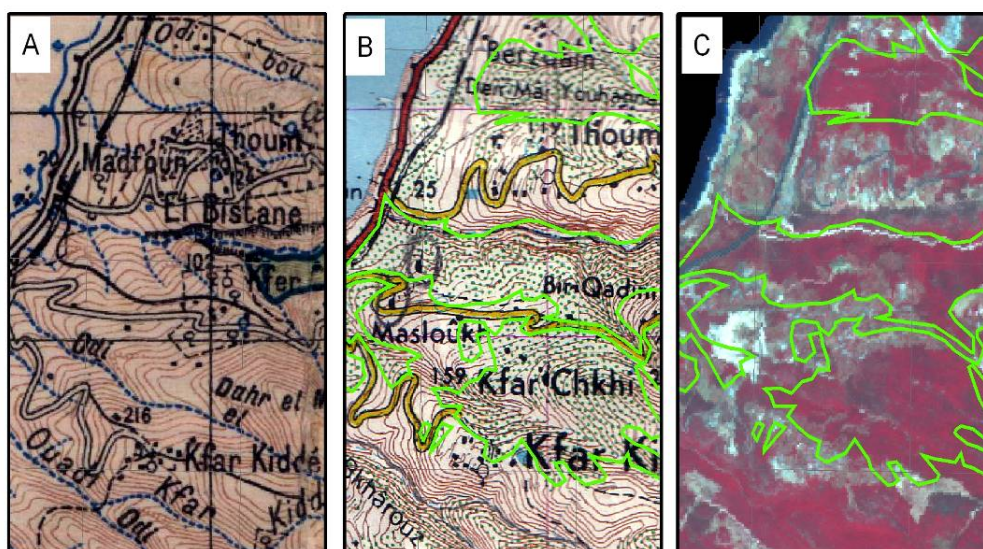
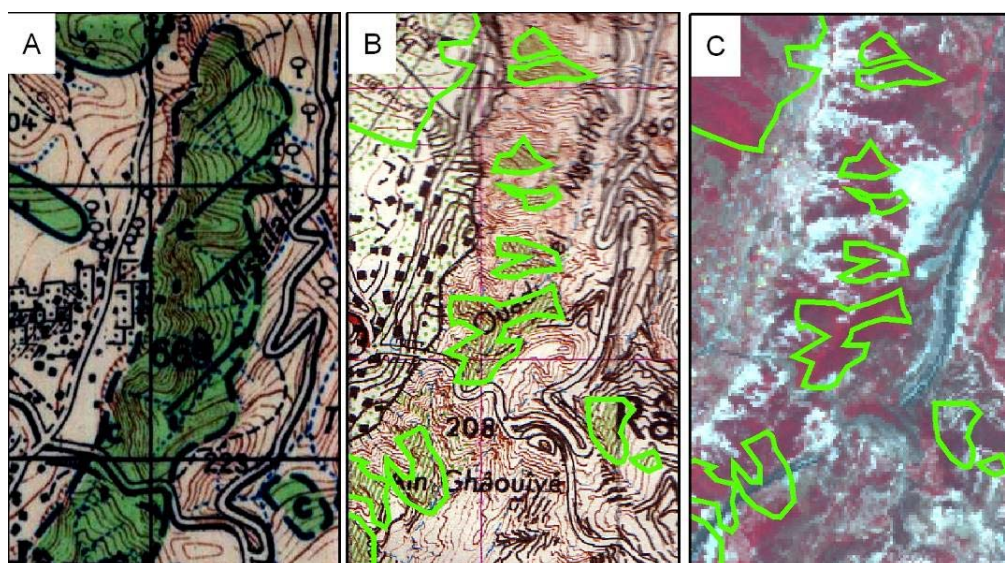


Figure 42. The three situation demonstrating differences between forest map of 1965 and topographic map of 1963 and the way of resolving these variations into improved new forest map of 1965.



Delineation of patches on topographic map

Figure 43. Absence of forest patches of forest map (A); appearance of the patches on topographic map (B); comparison to Spot 5 satellite image of 2003 (combination red=b1; green=b2 and blue=b3).



Delineation of patches on topographic map

Figure 44. Forest patches delineated as dashed lines on the forest map of 1965 was shown as aggregation of small patches on the topographic map (on screen representation of satellite image in combination red=b1; green=b2 and blue=b3).

The forest patches that required amendment were mainly distributed over the coastal part of the study area (Figure 45). In this part, the modifications of patch delineation were intensely found to the southwest where the altitude changes rapidly from the seashore inland. For example at southwest corner of the study area, the 400 m elevation above sea level is attained at 4 to 5 km far inland whereas toward the middle of the study area this distance becomes 11 to 16 km. This rugged and complex geomorphology to the southwest of the study area might be the cause behind the misdetection of the forest patch delineation. The areas of steep slopes cause changes in scale of adjacent aerial photos, which harm the stereoscopic interpretations (Avery, 1977). Shadows on one photograph of stereo-pairs will prohibit interpretations of spatial details. To the middle of the study area, the corrected patches are in areas of very steep slopes. Aerial photos might show complete shadow in such topographically rugged places, which might explain the missing forest patches on the 1965 forest map.

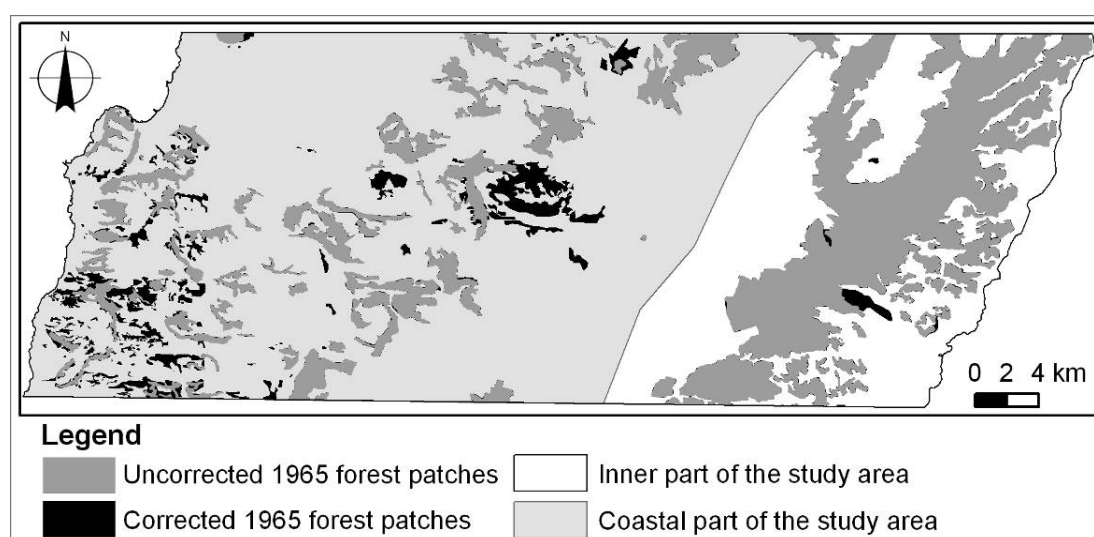


Figure 45. Both original and mended 1965 forest map.

The total forest area had a different of about 3868 ha between the original (not corrected) 1965 forest map and the corrected one (Figure 46). The area covered by oak coppices had increased by about 21% or by 3813 ha. Other forest types showed little or no changes. Juniper forests had shown difference in very limited surface areas.

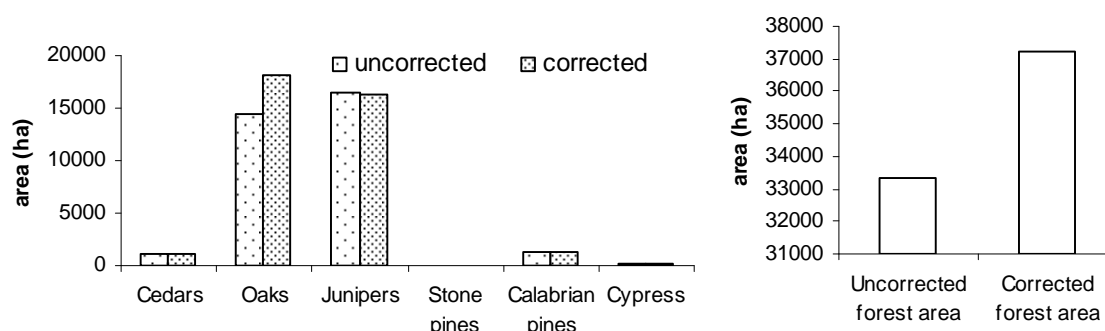


Figure 46. The forest area difference between both 1965 forest maps before and after correction.

An example was taken from the aerial photos, which show the forest delineation of oaks (Figure 47). The shadow has affected the accurate forest delineations where two forest patches (Oak 10-30% and Oaks >30% canopy closures) were drawn on the uncorrected forest map while the shaded patch was missed. Another example shows the 1965 forest map with its underlying aerial photo and the corresponding SPOT 5 satellite image. The false color composite of the satellite image showed the oak forests in dark red color. The dashed line forest patch on the uncorrected 1965 forest map was also compared to the satellite image for further accuracy after its resemblance to the topographic map (Figure 44 and 47). The mended forest map of 1965 was then produced (Figure 45).

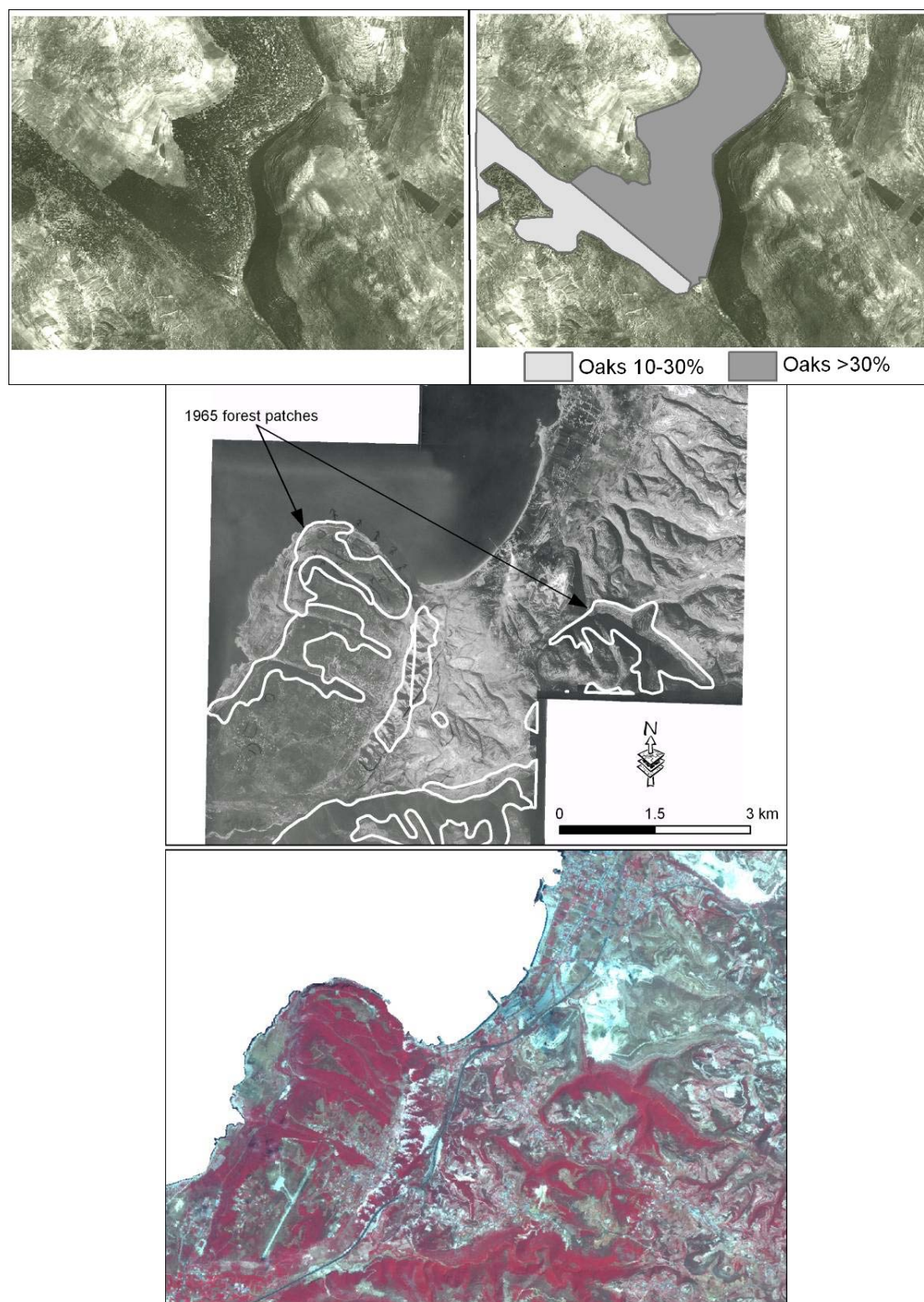


Figure. 47. Visual comparison between forest map of 1965, aerial photos of 1962 and satellite image of Spot 5 (color composition: R = green band, G = red band and B = near infrared band).

2.2. Classifying satellite images

The classification accuracy of the satellite images was performed for the years 1972 (MSS image), 1989 (TM image) and 2003 (Spot 5). The overall accuracy was 75%, 88% and 98% for the images 1972, 1989 and 2003, respectively (Table 22). The lower level of accuracy for the 1972 and 1989 image classification is related to the larger original pixel size of the images (Mehner *et al.*, 2004) and to the fact that the images were acquired 31 and 14 years before the field investigations in 2003. The classification accuracy showed important increase with the increase of satellite image spatial resolution from 80 (MSS) to 10 m (Spot 5). Confusion matrices were based on polygons of 15 to 20 pixels (see accuracy assessment paragraph page 95).

In classifying the 1972 image, the lowest value of producer's accuracy corresponded to cypress forests, which was under-classified. Cypress forests had very limited surface area and it was found in only one location, which reflected on having low overall accuracy. User's accuracy had low values for cedar and cypress forests. This also related to limited geographical distribution of these forests and to the fact that 80 m pixel size might overlapped them with other landcover-sensed data.

The producer's accuracy was also low for cedar and cypress forests for the classification of the image of 1989. Similarly, this was related to their limited surface coverage. The image had low differentiation between conifers such as cedars and pines, which lowered user's accuracy. Cedar and pine forest are sometimes located in mixed patches.

High producer's accuracy that obtained in classifying the Spot 5 satellite image was because of its high spatial resolution (10x10 m pixel size) and second because of the fact that field surveys were mainly performed in the same year of image acquisition. The lowest value of user's accuracy goes for oak and cedar forests classes, which were overestimated in the classification. Oak forests were found in narrow valleys where the image classification becomes difficult. Cedar forest has also limited geographical distribution and it could be found mixed with other conifers

Table 22. Confusion matrix for classification of 1987 Landsat TM and 2003 Spot 5 satellite images using six categories of landcover (figures are in pixels number).

| Ground control points | | | | | | | | | | | | | | | | | | | | | |
|-----------------------|---------------|---------------|-------------------|---------------|---------------|-------------------|---------------|---------------|-------------------|---------------|---------------|-------------------|---------------|---------------|-------------------|------------------|---------------|-------------------|-----------------|---------------|-------------------|
| Classified map | 1972 TM image | 1989 TM image | 2003 Spot 5 image | 1972 TM image | 1989 TM image | 2003 Spot 5 image | 1972 TM image | 1989 TM image | 2003 Spot 5 image | 1972 TM image | 1989 TM image | 2003 Spot 5 image | 1972 TM image | 1989 TM image | 2003 Spot 5 image | 1972 TM image | 1989 TM image | 2003 Spot 5 image | 1972 TM image | 1989 TM image | 2003 Spot 5 image |
| | Oaks | | | Pines | | | Cedars | | | Junipers | | | Cypresses | | | Non forest cover | | | User's accuracy | | |
| Oaks | 34 | 39 | 43 | 3 | 2 | 0 | 1 | 1 | 0 | 4 | 6 | 2 | 0 | 0 | 0 | 2 | 1 | 0 | 77 | 79 | 77 |
| Pines | 3 | 1 | 0 | 12 | 14 | 17 | 2 | 1 | 0 | 2 | 2 | 0 | 1 | 0 | 0 | 3 | 1 | 1 | 52 | 73 | 99 |
| Cedars | 2 | 1 | 1 | 2 | 0 | 0 | 3 | 3 | 4 | 1 | 2 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 30 | 50 | 80 |
| Junipers | 4 | 3 | 1 | 3 | 1 | 0 | 2 | 1 | 0 | 24 | 30 | 48 | 2 | 1 | 0 | 3 | 1 | 0 | 63 | 81 | 98 |
| Cypresses | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 1 | 1 | 2 | 0 | 0 | 0 | 16 | 100 | 100 |
| Non forest cover | 4 | 2 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 2 | 1 | 0 | 1 | 0 | 0 | 97 | 126 | 145 | 91 | 96 | 99 |
| Total* | 48 | 46 | 46 | 22 | 18 | 17 | 10 | 6 | 4 | 35 | 41 | 50 | 6 | 2 | 2 | 106 | 129 | 145 | 227 | 242 | 264 |
| Producer's accuracy | 70 | 84 | 93 | 54 | 77 | 100 | 30 | 50 | 100 | 68 | 73 | 96 | 16 | 50 | 100 | 91 | 97 | 100 | 75 | 88 | 98 |

*The figures signify number of pixels that were divided by 10; i.e., figures should be multiplied by 10 to obtain pixels number.

2.3. Changes in landcover areas

- Total area change of each forest type

Changes in forests and landcover information were derived following the analysis of the raster grids of 1965, 1972, 1989, 1998 and 2003 (Figure 48). The total forest area was found as follows:

- (1) In 1965, it was 35,851 ha, i.e., 26 % of the study area.
- (2) In 1972, it was 25,649 ha, i.e., 19 % of the study area.
- (3) In 1989, it was 26,745 ha, i.e., 19.6% of the study area.
- (4) In 1998, it was 27,321 ha, i.e., 20% of the study area.
- (5) In 2003, it was 27,698 ha, i.e., about 20.3% of the study area.

This corresponds to a loss of only 6% of the native forests during the period 1965–2003.

Although total forest area decreased, oak forest increased from 17,254 to 20,721 ha (13.4% to 15.2%) and cypress forest from 25 to 137 ha (0.0% to 0.1%) (Table 23).

Among all the forest types, juniper forest showed the most dramatic decrease, from 12.0% of the study area in 1965 to 3.5% in 2003. Pine forest decreased by 0.4% during the period 1965–2003. The non-forest cover increased from 72.5% to 79.7% from 1965 to 2003. Annual deforestation rate has changed between each period as follows: for 1965–1972 was $-1\% \text{ yr}^{-1}$, for 1972–1989 was approximately $0\% \text{ yr}^{-1}$, for 1989–1998 was 0.04% and for 1998–2003 was $0.06\% \text{ yr}^{-1}$. The overall rate of deforestation or forest regeneration was low.

Table 23. Estimated area of landcover types (class area, CA) in 1965, 1987 and 2003 in the study area.

| Land classes | 1965 | | 1972 | | 1989 | | 1998 | | 2003 | |
|--------------------|--------|------|---------|------|---------|------|---------|------|---------|------|
| | ha | % | ha | % | ha | % | ha | % | ha | % |
| Oak forest | 17,254 | 12.6 | 16,488 | 12.1 | 19,245 | 14.1 | 20,421 | 14.9 | 20,721 | 15.2 |
| Juniper forest | 16,369 | 11.8 | 7081 | 5.1 | 5421 | 3.9 | 4678 | 3.4 | 4727 | 3.5 |
| Cedar forest | 1,059 | 0.7 | 1018 | 0.7 | 1019 | 0.7 | 1069 | 0.8 | 1051 | 0.8 |
| Pine forest | 1,292 | 0.9 | 1027 | 0.7 | 1024 | 0.7 | 1023 | 0.7 | 1062 | 0.8 |
| Cypress forest | 25 | 0.0 | 35 | 0.0 | 36 | 0.0 | 130 | 0.1 | 137 | 0.1 |
| Non forest cover | 98,938 | 72.5 | 110,582 | 81.1 | 109,573 | 80.3 | 108,997 | 79.9 | 108,620 | 79.7 |
| Total forests only | 35,851 | 27.4 | 25,649 | 18.8 | 26,745 | 19.6 | 27,321 | 20.0 | 27,698 | 20.3 |

For further investigations, we digitized the forest patches found on the topographic map of 1/20,000 spatial scale. Similarly, to topographic map of 1/50,000, this map has woods and shrubs delineated on it. This step was for additional check on the 1965 forest map. The total forest area on the 1962 topographic map was 31,371 ha which less by 4,477 ha compared to the 1965 forest map. It should be mentioned that the 1962 topographic map and the 1965 forest have the same data source, i.e., the areal image overall Lebanon in 1962.

The difference was totally found distributed between juniper forests (78%) and oak forests (22%). The difference in oak forests delineation was found on the coastal part of the study area. We believe that the main reason behind the large difference in juniper is the fact that these forests area composed of widely separated trees (sometime more than 30 m as found on field investigations). Juniper forests cause problem in classification

when using low spatial resolution satellite images such as Landsat MSS and Landsat TM. The spatial resolution of Spot 5 satellite image was preferred for this forest type.

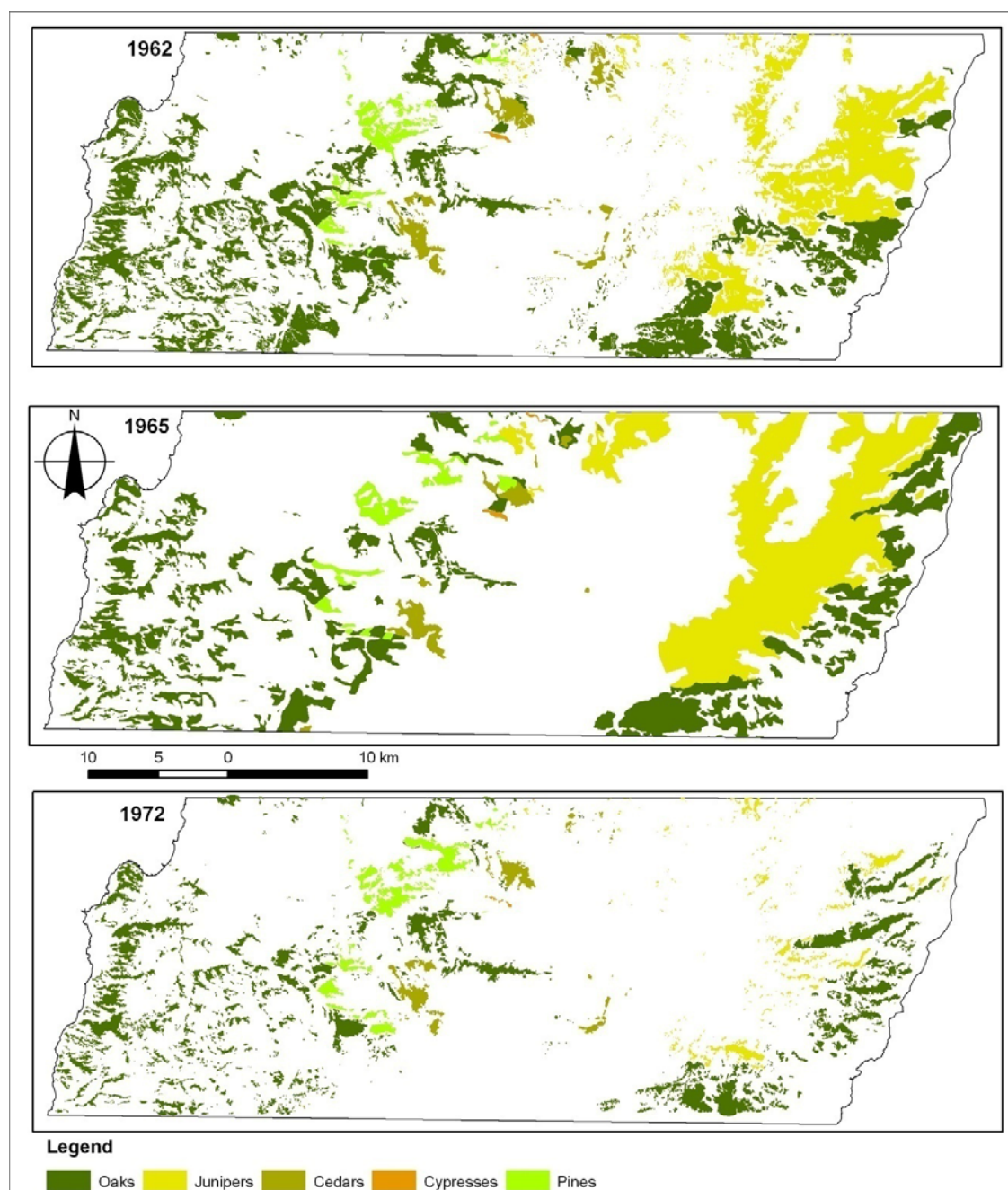


Figure 48. Variation in the spatial configuration of forests in 1962, 1965, 1972, 1989, 1998 and 2003.

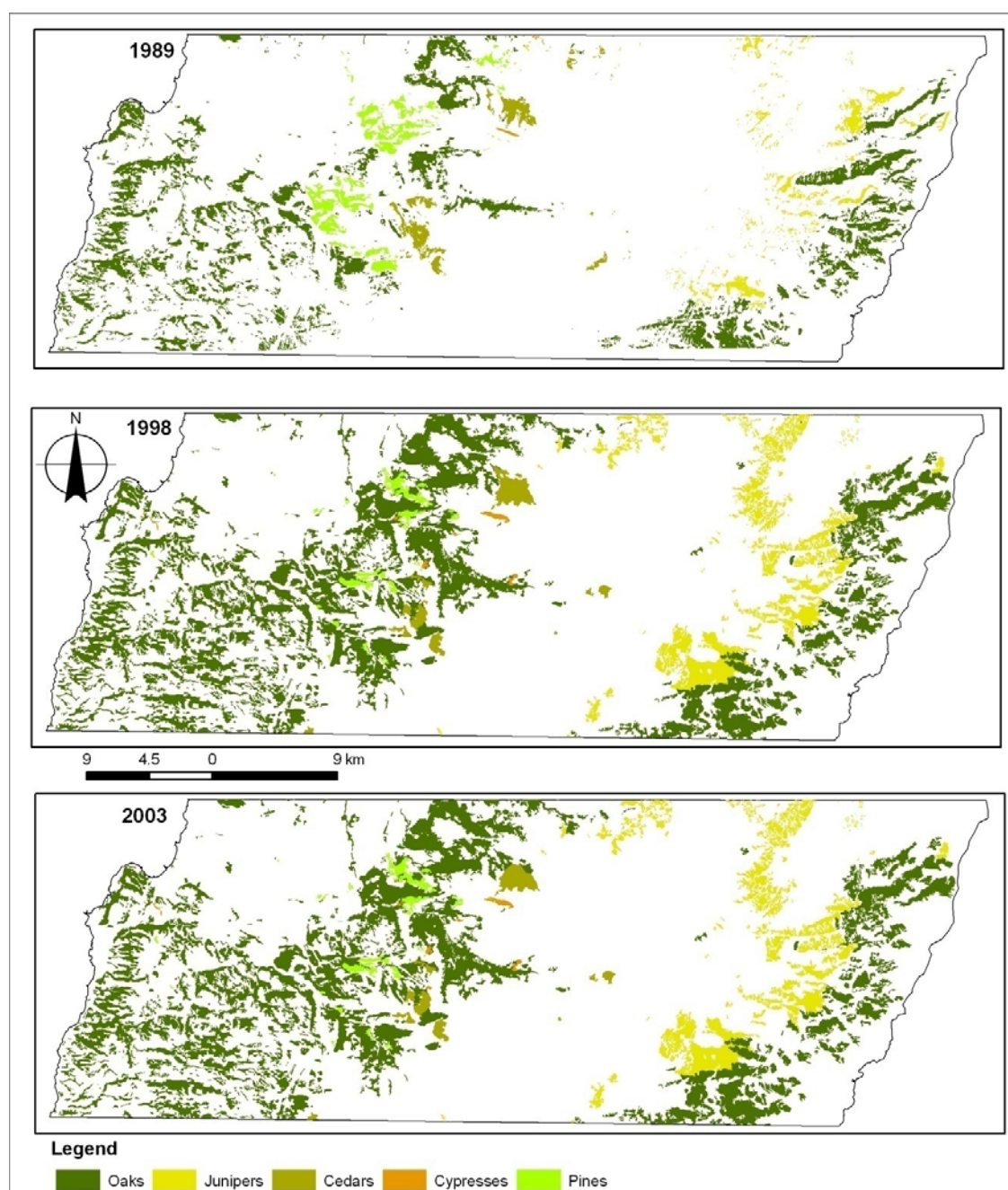


Figure 48. Continue.

The maps of figure 48 are obviously different and they might cause misunderstanding when only compared by direct observation. The 1965 map is at 1/50,000 scale that was derived from aerial photos. Forest patches were delimited by hand causing exaggeration of the area, especially at the region of juniper forests. The 1962 forest map is also derived

from the same source of data but it has a spatial scale of 1/20,000 that causes the juniper forests to be more accurately represented. The 1972 forest map has some area lost with regard to juniper forests. This is related to the fact that juniper trees are largely dispersed and the spatial resolution of the satellite image (used to obtain the 1972 map) is coarse (80 m pixel size). The juniper trees are lost and mixed to signatures that are reflected from the surrounding red soils. The 1989 map has 30 m pixel size which cause better juniper forest distinction and classification. The 1998 map has one forest patch that is wrongly designated as pines on the original map (the landcover of MOA/MoE, 2002) toward the oriental part (inner land) of the study area. This forest patch was corrected to oaks according to field truth and comparison to other forest maps.

- Transition matrices

Since a landcover map for 1965 does not exist, transition matrices were derived for the forest patches only, by searching inside the 1965 forest patches using landcover data of the years 1972, 1989, 1998 and 2003 (Table 24). Grass was the most prominent landcover that invaded the forest area during the entire period, i.e., grasslands were the most landcover type entered inside 1965 forest patches or replaced them. By the year 2003, grasslands replaced more than 30% of the juniper forests existed in 1965. Juniper forest appeared to be the most degraded within studied period. In total, more than 20% of the forest area was converted into grassland. Agriculture was the next landcover type that occupied 1965 forest area, accounting for about 6% of this area. Agriculture areas were mainly replacing oaks in incrementing trend starting from 1% in 1972 ending by more than 10% by 2003. Only about 1% of the forest area was converted to urban settlements. Oak forest was the most affected by urban expansion, with changes of 1.9% of oak forests area to urban uses.

Table 24. Transition matrix of forest patches over the studied periods.

| | | agriculture | | urban | | grass | | forests | | water | | Total 1965 |
|------|------|-------------|------|-------|-----|-------|------|---------|------|-------|-----|---------------|
| | | (ha) | % | (ha) | % | (ha) | % | (ha) | % | (ha) | % | (ha) |
| Oaks | 1972 | 217 | 1.2 | 4 | 0.0 | 71 | 0.4 | 16,962 | 98.3 | 0 | 0.0 | 17,254 |
| | 1989 | 1725 | 9.9 | 249 | 1.4 | 1727 | 10.0 | 13,553 | 78.5 | 0 | 0.0 | |
| | 1998 | 1651 | 9.5 | 300 | 1.7 | 1904 | 11.0 | 13,396 | 77.6 | 3 | 0.0 | |
| | 2003 | 1784 | 10.3 | 326 | 1.9 | 2017 | 11.6 | 13,123 | 76.0 | 4 | 0.0 | |

Table 24. continue.

| | | | | | | | | | | | | |
|-----------|------|------|-----|-----|-----|------|------|--------|------|---|-----|--------|
| Junipers | 1972 | 1 | 0.0 | 0 | 0.0 | 1051 | 6.4 | 15,317 | 93.5 | 0 | 0.0 | 16,369 |
| | 1989 | 124 | 0.7 | 3 | 0.0 | 4597 | 28.1 | 11,645 | 71.1 | 0 | 0.0 | |
| | 1998 | 273 | 1.6 | 8 | 0.0 | 6271 | 38.3 | 9817 | 60.0 | 0 | 0.0 | |
| | 2003 | 294 | 1.8 | 12 | 0.1 | 6312 | 38.5 | 9750 | 59.5 | 1 | 0.0 | |
| Cedars | 1972 | 0 | 0.0 | 0 | 0.0 | 50 | 4.7 | 1009 | 95.2 | 0 | 0.0 | 1059 |
| | 1989 | 4 | 0.3 | 0 | 0.0 | 97 | 9.1 | 958 | 90.4 | 0 | 0.0 | |
| | 1998 | 7 | 0.6 | 0.1 | 0.0 | 108 | 10.1 | 944 | 89.1 | 0 | 0.0 | |
| | 2003 | 6 | 0.5 | 0 | 0.0 | 103 | 9.7 | 950 | 89.7 | 0 | 0.0 | |
| Pines | 1972 | 11 | 0.8 | 0 | 0.0 | 8 | 0.6 | 1273 | 98.5 | 0 | 0 | 1292 |
| | 1989 | 27 | 2.1 | 1 | 0.1 | 17 | 1.3 | 1247 | 96.5 | 0 | 0 | |
| | 1998 | 37 | 2.8 | 2 | 0.1 | 24 | 1.8 | 1229 | 95.1 | 0 | 0 | |
| | 2003 | 41 | 3.2 | 4 | 0.3 | 31 | 2.3 | 1216 | 94.1 | 0 | 0 | |
| Cypresses | 1972 | 0 | 0.0 | 0 | 0.0 | 4 | 16.0 | 21 | 84.0 | 0 | 0.0 | 25 |
| | 1989 | 0 | 0.0 | 0 | 0.0 | 2 | 8.0 | 23 | 92.0 | 0 | 0.0 | |
| | 1998 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 25 | 100 | 0 | 0.0 | |
| | 2003 | 0 | 0.0 | 1 | 4.0 | 1 | 4.0 | 23 | 92 | 0 | 0.0 | |
| Total | 1972 | 229 | 0.6 | 4 | 0.0 | 1184 | 3.2 | 34582 | 96.1 | 0 | 0.0 | |
| | 1989 | 1880 | 5.2 | 253 | 0.7 | 6440 | 17.3 | 27426 | 76.1 | 0 | 0.0 | |
| | 1998 | 1968 | 5.4 | 310 | 0.9 | 8307 | 23.1 | 25411 | 70.5 | 3 | 0.0 | |
| | 2003 | 2125 | 5.9 | 343 | 0.9 | 8464 | 23.5 | 25062 | 69.6 | 4 | 0.0 | |

The period from 1972 to 1989 is when agriculture has largely (to about 5% of area) entered forests of 1965. The yearly rate of forest replacement by agriculture decreased from 0.3% to 0.02% area/yr⁻¹. The same period also showed more than 14% grassland increase on the extent of 1965 forests; the yearly rate on change for grasslands also decreased from 0.8% to 0.3% area/yr⁻¹ when moving from period 1972-1989 to the period 1989-1998 and 2003. Urban expansion replaced 0.7% of 1965 forest between 1972 and 1989; where urban is still slowly replacing forests after 1989 where only 0.2% of this forest area has changed to urban between 1989 and 1998. As a recent development, some water reservoirs had appeared inside the oak forests in 1998 and 2003 and only very limited area of junipers by the year 2003.

The remaining oak forest was 13,123 ha by the year 2003; this area was 17,254 ha in 1965 (Table 22). This is what we called inside forest patch changes. However, the total oak forests area increased to reach 20,721 ha in 2003 (Table 21). The 7598 ha (20,721 – 13,123) difference in oaks area is what possibly regenerated on the outside of the 1965 forest patches by the year 2003.

2.4. Regeneration of 1965 forests

Since oak forests showed total area increase between 1965 and 2003, we searched for oak regeneration to the outside of the 1965 forests. This could also be related to the fact that oak forests have important regeneration capability (Liphschitz and Biger, 1990; Jomaa *et al.*, 2008b).

Other forest types might also appear or have some new area growth to the outside of the 1965 forest patches, although their total area showed decrease. Therefore, we searched, outside the 1965 forest patches, each 100 m band, starting from the edge of the 1965 forest patches and recorded the area of each forest type plus their total patch number (Figure 49). Oak forest was present in large areas (4920 ha) within the first 100 m band. Oaks at this rang had about 600 patches. Pine and cedar forest appear at 400-500 m distance only because of reforestation, with only 48 and 51 ha respectively. Regenerated junipers were attached to the edge of the 1965 jumper forests patches. Oak forests occur to distances of more than 1000 m from the 1965 forest patches. In 2003, the total number of patches that occur outside the 1965 forest patches attains 90% at 600-700 m distance. In other words, the majority of the outer patches or regenerated forests in 2003 are located within 0-700 m distance outside the 1965 forest patches. Outer patches (on the outside of 1965 forest patches) are either regenerated or reforested, depending on the forest type.

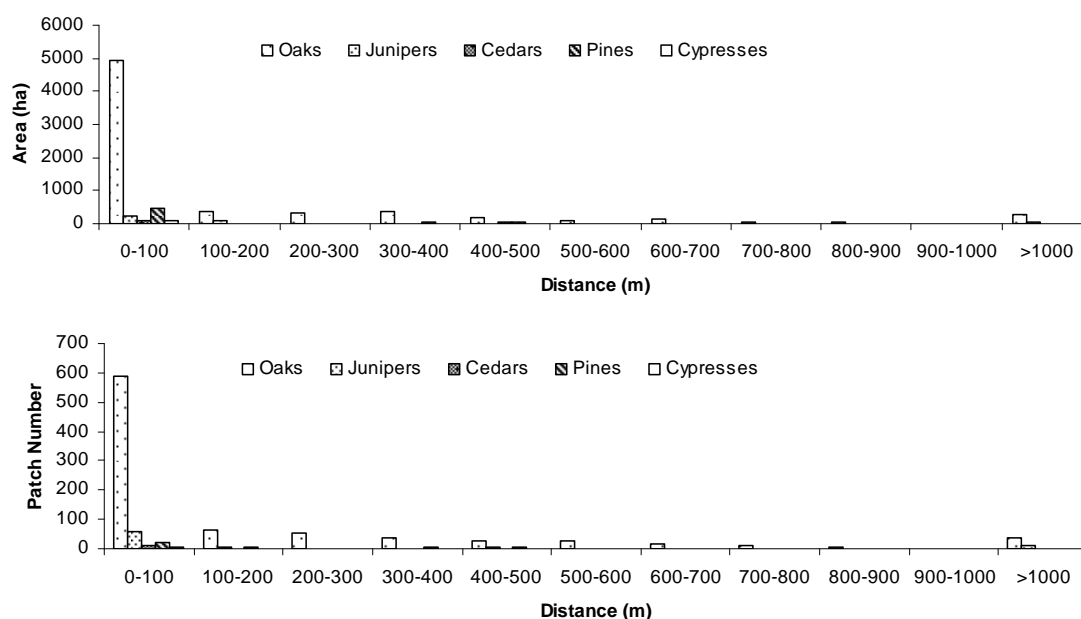


Figure 49. Area in hectares of 2003 patches located outside 1965 forest patches (top). Number of patches in 2003 located in each 100 m distance band outside the 1965 forest patches (bottom).

2.5. Forest fragmentation

As evident from the obtained results the total forest area decreased but some forests (oaks) showed area increase. Through the successively investigated years, forest fragmentations are more comprehensively understood.

Number of landscape forest patches showed increase by 7% in the first period of the study, i.e., 1965-1972 (Table 25). Another 76% increase of forest patch number had occurred up to the year 1989. Only 10% increase of forest patch number appeared between 1989 and 1998. This corresponds to an annual increase rate in the number of forest fragments as follows: $1\%.\text{yr}^{-1}$ in 1965-1972, about $5\%.\text{yr}^{-1}$ in 1972-1989, $1\%.\text{yr}^{-1}$ in 1989-1998 and $0.2\%.\text{yr}^{-1}$ in 1998-2003.

Mean patch size decreased from 219 to 81 ha during the entire period 1965–2003. However, the majority of patch size decrease has happened between 1972 and 1989. The change rates of the patch size started in the first period by $1.4 \text{ ha}.\text{yr}^{-1}$ and then highly increased to reach about $6 \text{ ha}.\text{yr}^{-1}$ in the second period 1972-1989. The annual rate of

patch size showed a trend of slowing down between 1989 and 2003. This rate was 2 ha in 1989-1998 and reached 0.6 ha in 1998-2003.

Although mean patch size was the highest in 1965, 74% of the forest area was found in patches of less than 100 ha. The remaining forests occurred as: 21% in patches between 100 and 500 ha, 3% in patches between 500 and 1000 ha, and 2% in patches >1000 ha. The number of small patches, between 0 and 100 ha, has tripled during the period from 1965 to 2003 (from 210 to 624 patches). The number of small patches (0-100 ha) increased to reach 88% and 89% of the total patches in 1989 and 2003 respectively. Another important increase has occurred in patches of 100-500 ha in size (from 64 in 1965 to 23 in 2003).

Table 25. Landscape metrics for the observation years.

| Year | Study area part | TA (ha) | LPI % | NP | MPA (ha) | AWMSI | AWMPFD | MNN (m) | MPI | SDI | SEI | IJI |
|------|-----------------|-------------|----------|------|-------------|-------|--------|------------|-------|------|------|-------|
| 1965 | all | 1,363,181.9 | 15.4 | 284 | 219 | 3.4 | 1.1 | 600 | 78.2 | 0.95 | 0.59 | 49.48 |
| 1965 | inland | 489,766.7 | 29.1 | 42 | 314 | 5.2 | 1.2 | 340 | 85.1 | 0.96 | 0.64 | 54.2 |
| 1965 | coast | 843,415.0 | 8.4 | 242 | 180 | 2.4 | 1.1 | 245 | 81.2 | 0.88 | 0.57 | 47.2 |
| 1972 | all | 1,363,181.9 | 14.1 | 307 | 209 | 3.5 | 1.3 | 545 | 84.2 | 0.91 | 0.57 | 48.1 |
| 1972 | inland | 489,766.7 | 27.1 | 51 | 306 | 4.2 | 1.4 | 345 | 81.1 | 0.90 | 0.59 | 52.1 |
| 1972 | coast | 843,415.0 | 8.6 | 256 | 174 | 2.1 | 1.3 | 231 | 74.1 | 0.82 | 0.54 | 48.1 |
| 1989 | all | 1,363,181.9 | 11.0 | 1301 | 104 | 5.1 | 1.2 | 484 | 167 | 0.84 | 0.45 | 46.2 |
| 1989 | inland | 489,766.7 | 18.1 | 214 | 201 | 4.2 | 1.3 | 321 | 84.2 | 0.91 | 0.57 | 45.1 |
| 1989 | coast | 843,415.0 | 5.1 | 1087 | 95 | 5.3 | 1.4 | 276 | 87.1 | 0.84 | 0.42 | 47.1 |
| 1998 | all | 1,363,181.9 | 10.43 | 1455 | 84 | 5.2 | 1.2 | 457 | 195.3 | 0.87 | 0.43 | 47.1 |
| 1998 | inland | 489,766.7 | 15.2 | 275 | 204 | 4.2 | 1.4 | 465 | 185.1 | 0.85 | 0.42 | 49.1 |
| 1998 | coast | 843,415.0 | 6.1 | 1180 | 96 | 3.2 | 1.3 | 281 | 154 | 0.91 | 0.47 | 47.1 |
| 2003 | all | 1,363,181.9 | 10.2 | 1472 | 81 | 5.2 | 1.1 | 456 | 214 | 0.83 | 0.41 | 46.8 |
| 2003 | inland | 489,766.7 | 14.2 | 286 | 201 | 5.6 | 1.4 | 424 | 174 | 0.84 | 0.45 | 49.1 |
| 2003 | coast | 843,415.0 | 5.7 | 1186 | 81 | 4.8 | 1.3 | 274 | 159 | 0.86 | 0.40 | 44.2 |

TA: total landscape area; LPI: largest patch index; NP: number of patches; MPA: mean path area; AWMSI: area weighted mean shape index; AWMPFD: area weighted mean patch fractal dimension; MNN: mean nearest neighbor; MPI: mean proximity index; SDI: Shannon diversity index; SEI: Shannon evenness index; IJI: interspersed and juxtaposition index.

The landscape was subjected to fragmentation as the number of patches increased together with decreasing in mean patch area or size. Both Shannon's diversity and Shannon's evenness indices decreased, which indicates a lesser proportional distribution of area among patch types or the dominance of the landscape by a single patch type.

The decrease in mean patch area was associated with a reduction in the largest-patch index by 32% from 1965 to 2003. The mean nearest neighbor index decreased because of the increase in the number of patches. This combination of landscape spatial reconfigurations is attributed to fragmentation of larger patches and not to a higher rate of aggregation of patches. In addition, the interspersion and juxtaposition index (IJI) decreased, indicating that the spatial distribution of adjacencies among patch types became increasingly uneven. This result was related to fragmentation of larger patches and to dominance of one patch type.

At the class level, patch number increased with the decrease in mean patch size during the entire investigated period (Figure 50). It is evident that oak and junipers forests undergone important fragmentation phenomenon. Oak forest number of patches increased by 5 times, although, it already has small sized patch. Junipers had relatively large patch size while their number of patches increased by almost 20 times.

During the entire period, juniper forests mean nearest neighbor (from 3000 to 500 m) and juxtaposition (from 20 to 4) indices decreased dramatically, which indicate the appearance of many small patches with uneven distribution during both periods. Oak forest showed a minor decrease in the mean nearest neighbor index (380-364 m) while the IJI increased (58-76), indicating the presence of more patches with an even distribution. Pine and cedar forest showed similar trends with increases in MNN and decreases in IJI. Cypress forest experienced increases in both MNN and IJI. Pine, cedar, and cypress forests were reforested in different locations.

Area-weighted mean patch fractal dimension for all forest types showed a change of less than 0.1 throughout the study period. The shape complexity decreased during the entire period. Juniper forests had the simplest forest patch shape with regard to all forest patch types.

It was found that coastal part of the study area is being fragmented more rapidly when compared to inland. Number of patches at the coastal part increased by 5 times while inlands increased by about 7 times. However, at the coastal part mean patch area decreased by more than twice the original size during the entire studied period. Inner land part had decreased only by 1.3.

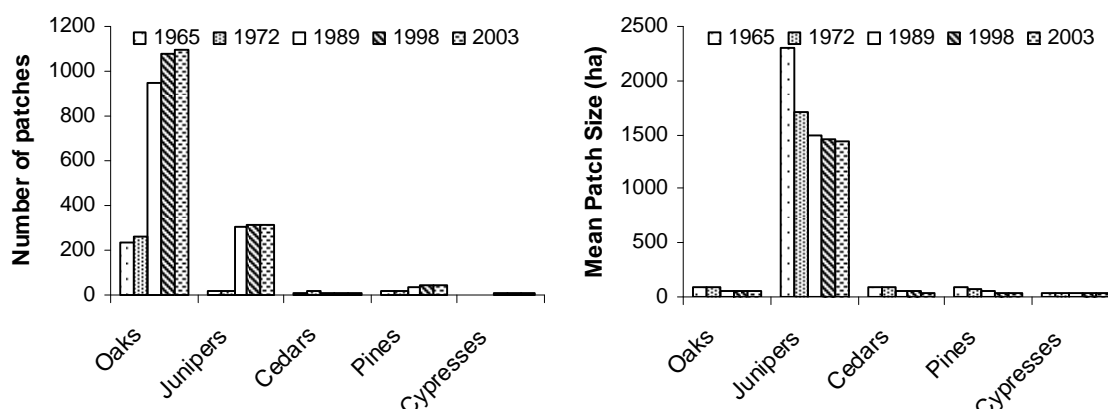


Figure 50. Comparison of forest types Patch Number and Mean Patch Area in the investigated years.

2.6. Patch related indices and forest changes

Forest changes through the years were investigated for their possible relation to patch based indices on both parts of the study area the inner land (oriental) and costal part (occidental). Forest changes do not depend on patch based spatial characteristics such as (Figure 51, 52 and 53):

1. patch size,
2. patch shape,
3. linearity of the patch and
4. patch topographic features.

Forests at any part of Lebanon (occidental or oriental) do not change with time based on the spatial characteristics of a patch. It is, therefore, other related factors that cause forest loss and changes. Unlike tropical, changes in Mediterranean forests have external variables that could not be detected using only spatial landscape indices. This fact takes us back to the following question: how applicable or usable the landscape indices in the Mediterranean region? The ecological characteristics of the Mediterranean forests could not be deliberated without including the human or anthropic effects. This is one of the most important reasons why landscape indices are rarely applied around the Mediterranean.

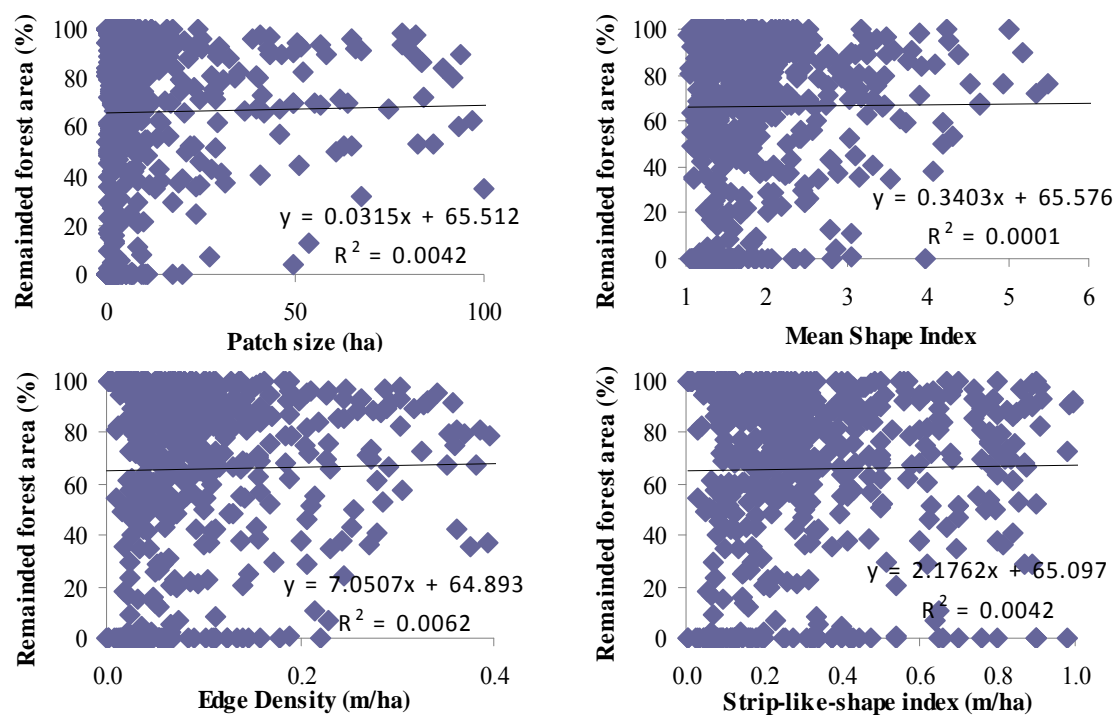


Figure 51. Occidental forests (coastal part) loss with relation to spatial indices.

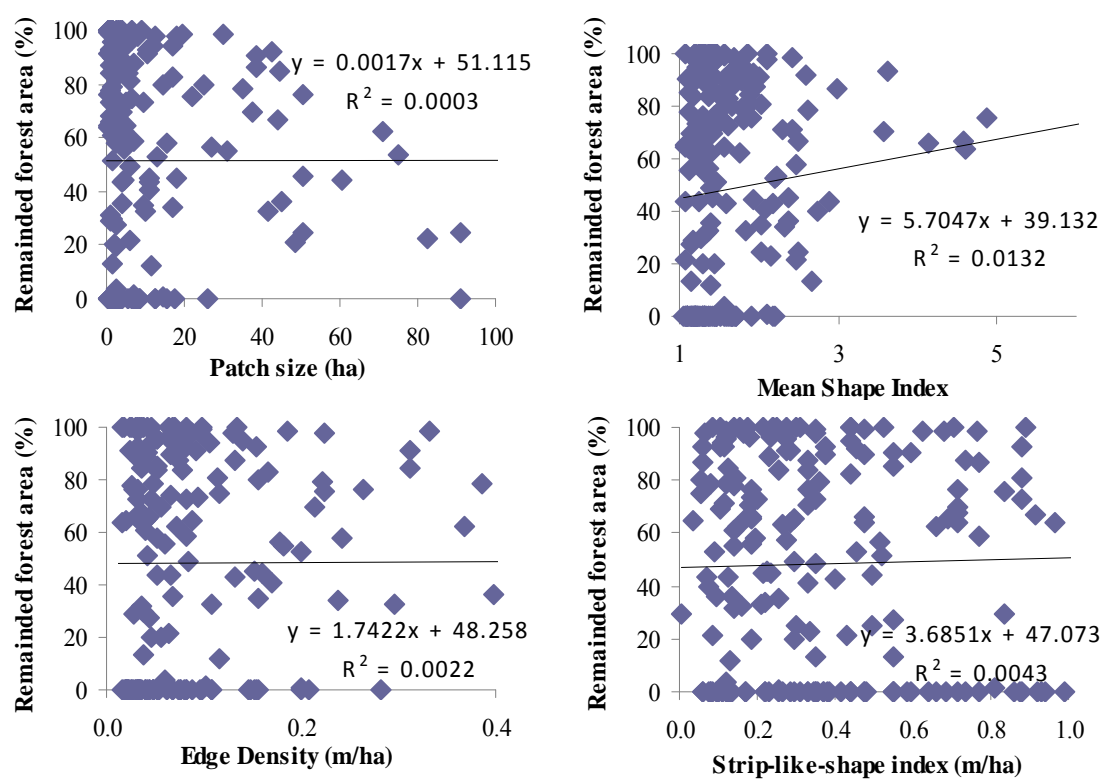


Figure 52. Oriental forests (coastal part) loss with relation to spatial indices.

Mediterranean forests (especially in Lebanon) are mainly found on topographically complex mountain lands. Therefore, we developed a landscape index that reflects the geomorphological characteristics of such mountain forests. The relative number of topographic faces (RTF) is an important geomorphological characteristics of a forest patch that might affect changes and human interference. It is usually considered that anthropic interferences toward forests occur on areas of easier access or of less topographic complexity. We found that forest changes do not depend on land geomorphological characteristics. Human interferes anywhere or in any forest area without relation to the topographic characteristics of the forest.

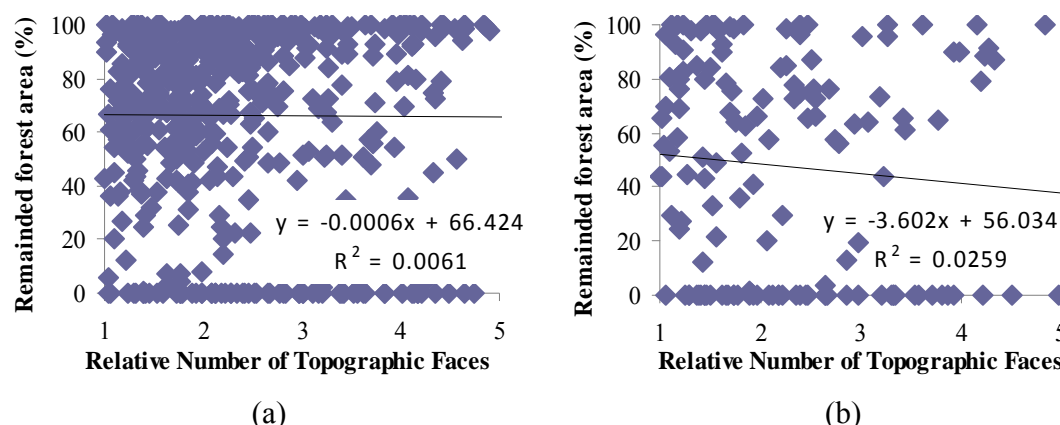


Figure 53. occidental (a) and oriental (b) forests loss with relation to topographic complexity.

2.7. Limitation of the previous juniper forests delineation methods

- *Juniper forests delineation*

Juniper forests were found to be the most affected and changed throughout the study period. We noticed that the northeast of the study area where junipers exist, the 1965 forest map delineates large patches when compared to the next forest map of 1972 (Figure 47).

Field observations revealed that juniper trees are largely spaced, reaching 60 m in various locations. Generally, the shortest tree distance is 20 m. This fact could be the

main reason why large difference in juniper surface area was found, comparing same juniper forests on different maps that have different scale (1/50,000 and 1/20,000) but go back for the same year, i.e., 1962. The difference in total area of juniper forests was 5942 ha between both maps.

Consequently, fragmentation analyses of juniper forests could largely be questioned. Delineating juniper forests is an important problem in Lebanon where it is not yet solved. We suggest a method to resolve this difficulty. Our method opens the road for better future delineation of juniper forests and so better monitoring.

To delineate and map juniper forests, it is important first to set the spatial scale on fixed level. For example, a 1/20,000 spatial scale map requires that the author has to draw a circle of 20 m in diameter. Every two successive (neighboring) juniper trees have to fit within the 20 m circle in order to be included in one forest patch. This mapping procedure causes to have snake like patches, in some places, running from juniper tree to another (Figure 54). This method standardizes the delineation of the juniper forests and constitutes homogeneous fairest patches. High spatial resolution satellite images are required to perform this tree-to-tree forest mapping methodology.

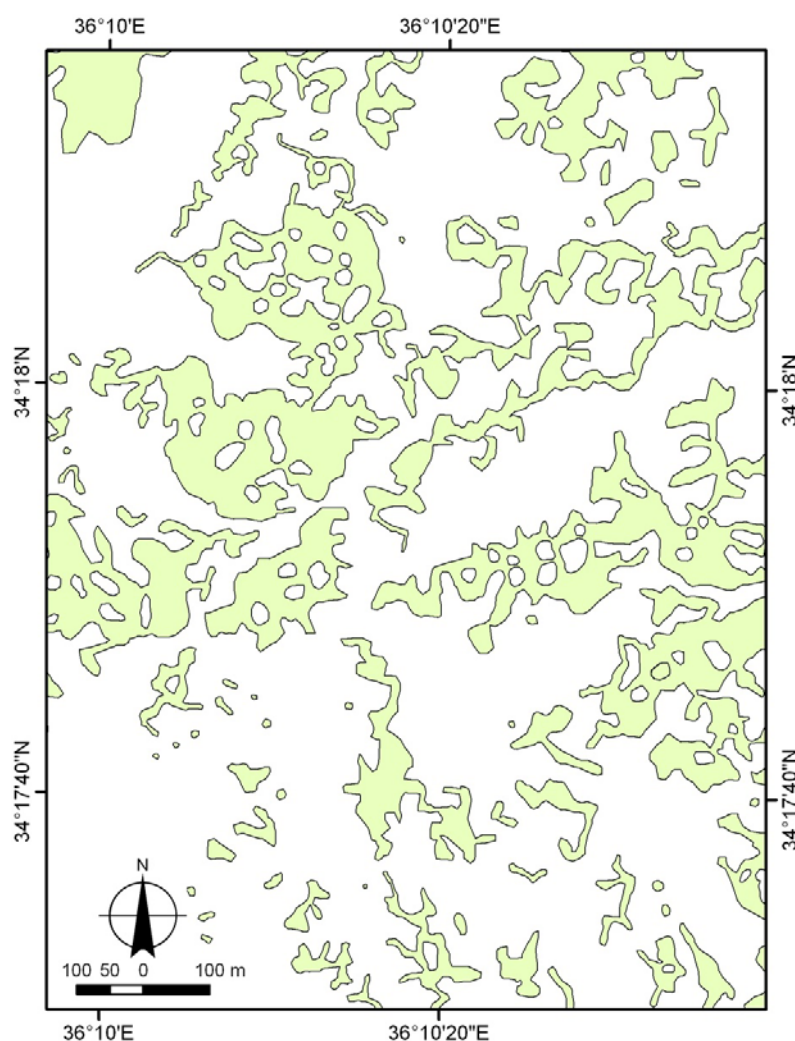


Figure 54. Junipers delineation on 1/20000 spatial scale.

2.8. Hemerobiotic state of forest patches

For knowing the hemerobiotic state of the forest patches, the forest map of 1965 was used and roads that we digitized from the topographic map of the same year. The number of forest patches that have roads passing across them were 110/284 patches (Table 26). Coastal and inner land parts of the study area do not differ in their road intrusion inside forests.

We computed Road Density (RD) inside each of the forest patch. The RD has ranged between 0 and 3.3 where the number of patches in each of the following selected ranges was: (i) 65 patches in 0-0.3, (ii) 26 patches in 0.3-0.5 and (iii) 19 patches in 0.8-3.3.

When the RD increases inside forest patch, this means a patch is further deviating from the natural hemerobiotic state to more anthropic disturbed state.

The number of patches was also counted for each forest canopy closure. This was also considered for the hemerobiotic status of a forest patch. Low canopy closure patch (10-30%) that has a road across, it means further deviation from natural hemerobiotic state.

Table 26. The number of forest patches for different ranges of road length.

| Canopy closure | Area part | Road length (m) | | | | | | | | | | |
|----------------|-----------|-----------------|---------|---------|---------|---------|---------|---------|---------|---------|----------|-------|
| | | 0-100 | 100-200 | 200-300 | 300-400 | 400-500 | 500-600 | 600-700 | 700-800 | 800-900 | 900-1000 | >1000 |
| 10-30% | coast | 5 | 3 | 2 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 9 |
| | inland | 4 | 3 | 1 | 3 | 1 | 0 | 3 | 1 | 2 | 2 | 6 |
| >30% | coast | 6 | 6 | 2 | 4 | 4 | 0 | 0 | 0 | 3 | 0 | 12 |
| | inland | 1 | 1 | 0 | 1 | 0 | 0 | 3 | 1 | 0 | 2 | 7 |

The hemerobiotic state might also change with the distance to urban settlements. We considered five different degradation levels according to the percent of forest in 2003 that remained inside the limits (boarder) of the 1965 forest patches. Thus, each forest patch of 1965 was overlaid on the 2003 forests and five degradation levels were chosen accordingly: very-degraded 0-20% forest remaining inside, degraded 20-40%, low-degraded 40-60%, moderately degraded 60-80% and not-degraded 80-100% (Figure 55). The percent number of patches from each level was plotted on distance to urban settlements. Highly degraded forest patches were highly found on the most distant point from urban settlements. Therefore, forest patch changes showed to be independent from their distance to urbanize areas.

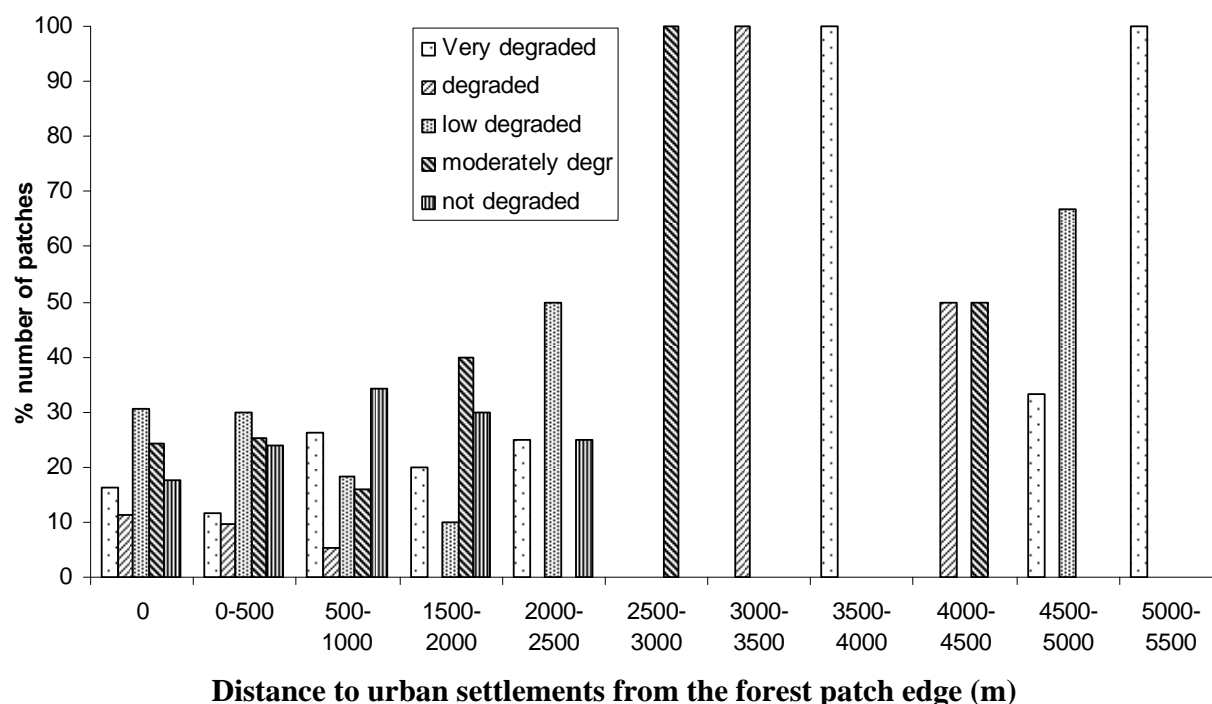


Figure 55. Degradation of forest patches based on the distance (m) between forest patches and urban settlements in 1962.

Linear features within a forest patch were detected from high-resolution satellite image Ikonos of the year 2005. The linear features were the result of indirect human interference through constructing nearby roads or quarries (Figure 56). It was evident that the illustrated for patch, as an example, had linear feature on one end of the patch. The road is found on top of the forest patch. To the left side of the image, a quarry had its effect down slope cutting the forest patch in wider linear feature that become like a strip form. This also was considered as another sign of hemerobiotic state of a forest patch.

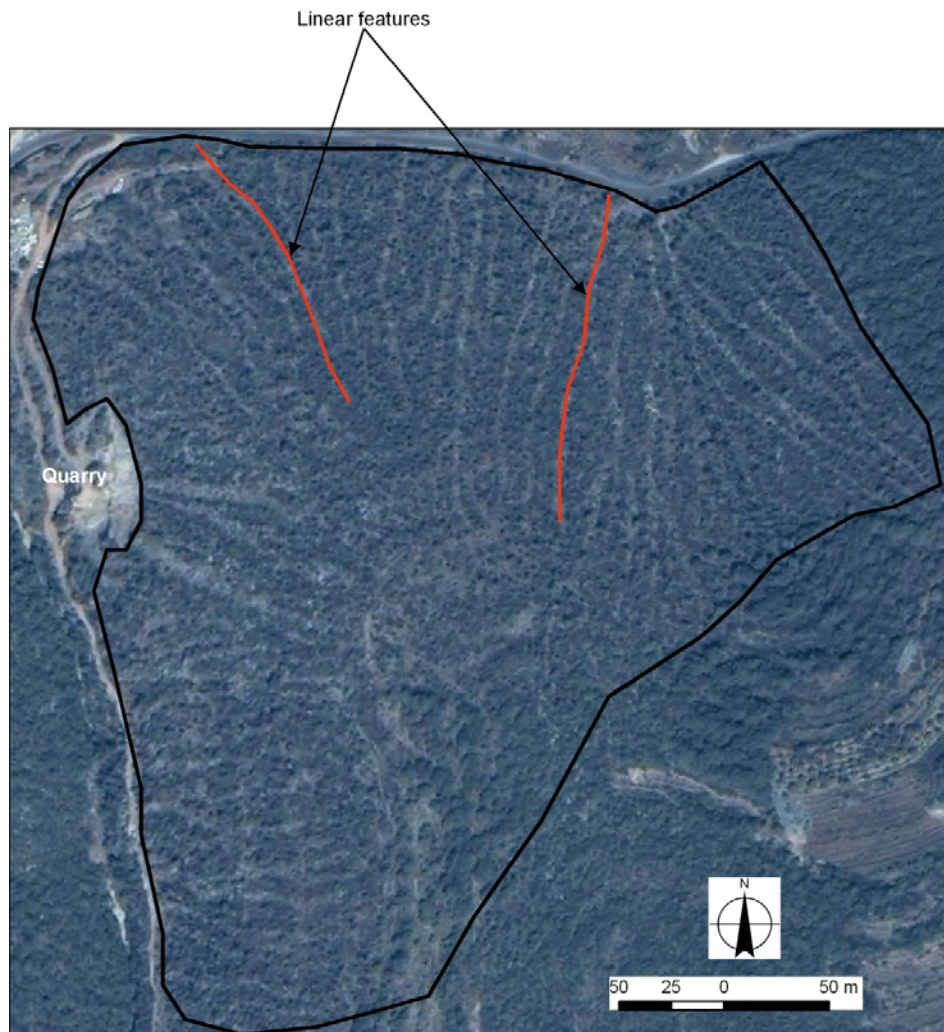


Figure 56. Linear features detected on the inside of the forest patch.

Forest patches showed a form like intrusions. Intrusions are gaps between dents that might be naturally formed because of valleys or after fire and might be artificially shaped after forest degradation. Intrusions might be caused by agriculture or urban constructions as abrupt breaks in (Figure 57). These abrupt forms constitute what we called forest patch dents, which become the most sensitive part of the forest and easily affected by disturbances of the surroundings. The forest patch could be considered that it entered a fragmentation phenomenon.

We considered dents of 200 m long and more than 80 m of width. The dent is an area of the forest that has small core area or no core area at all. It increases the edge length of

a forest. Almost 44% of forest patches had dents. The overall number of dents was 88. Only one polygon had 20 dents.

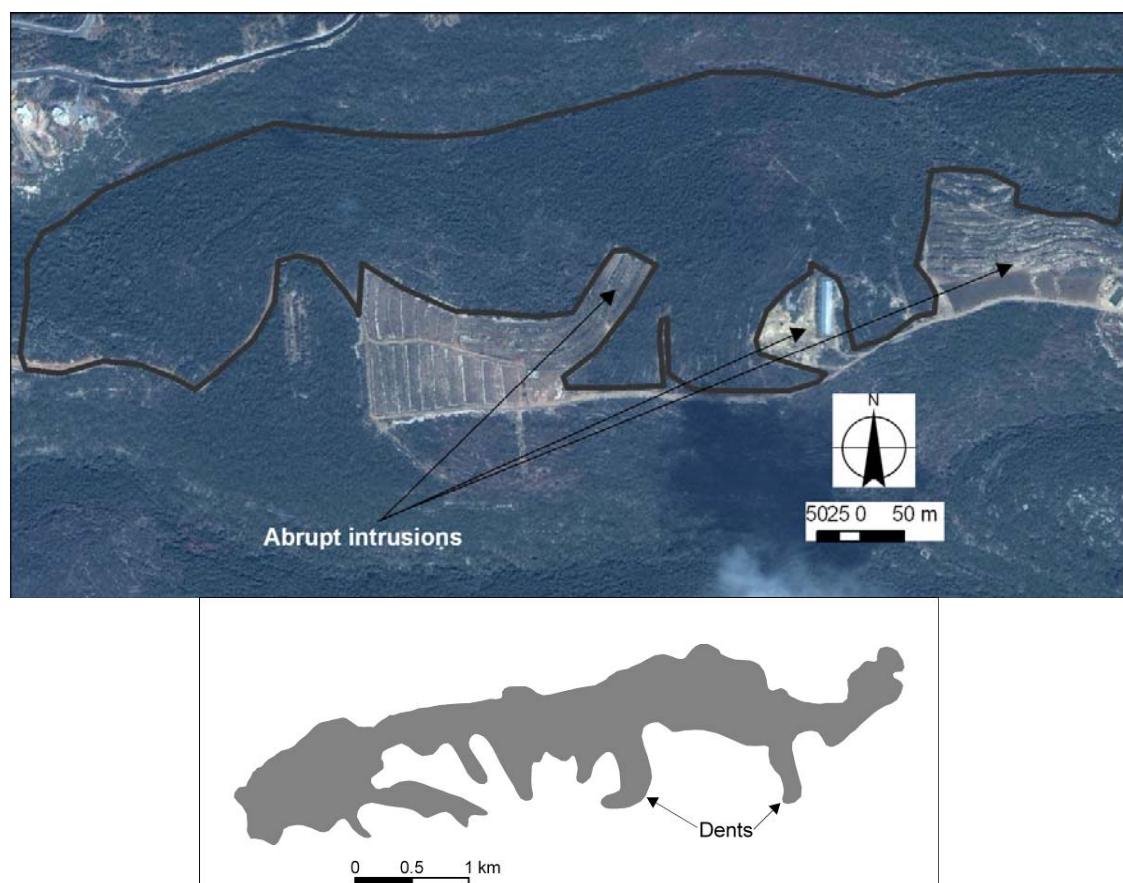


Figure 57. Intrusion and dents in a forest patch.

2.9. NDVI changes

We used NDVI to detect forest fire areas and excavations within a forest patch. An example of forest fire event happened between 2003 (the acquiring date of Spot 5 satellite image) and 2005 (Ikonos image acquiring date) (Figure 58). This fire was approximately 5 ha deducted from one forest patch as a sudden event. This is another reason why it is important to study forest spatial configuration on patch and landscape level.

Oak forests regeneration might also be detected through NDVI. Forests were burned between the years 1997 and 2000 (Figure 59). Three years after fire, NDVI increased

from below 0 to more than 0.2. In 2005, this same forest appeared as if it had no fire events.

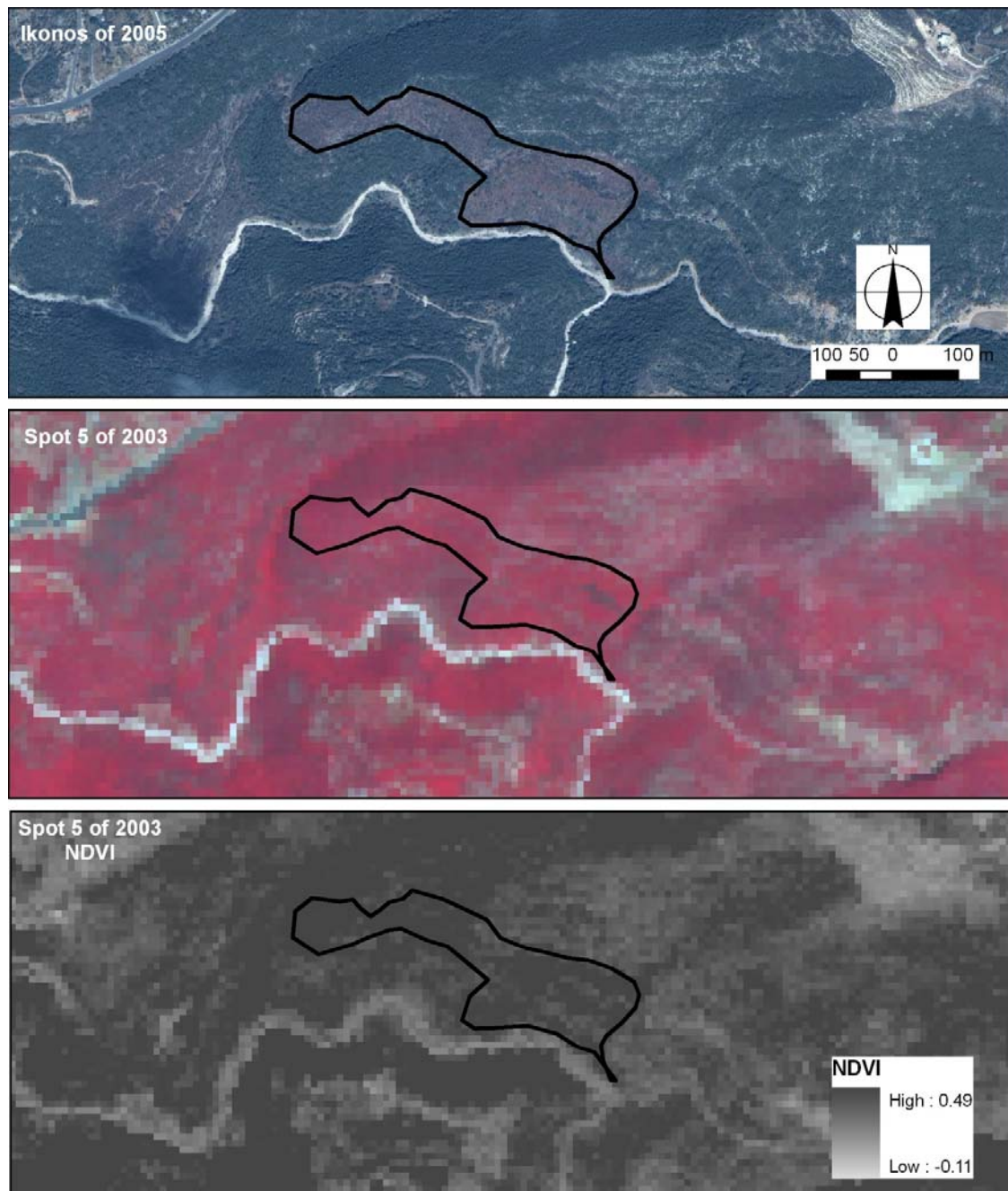


Figure 58. Forest fire events happened between 2003 and 2005.

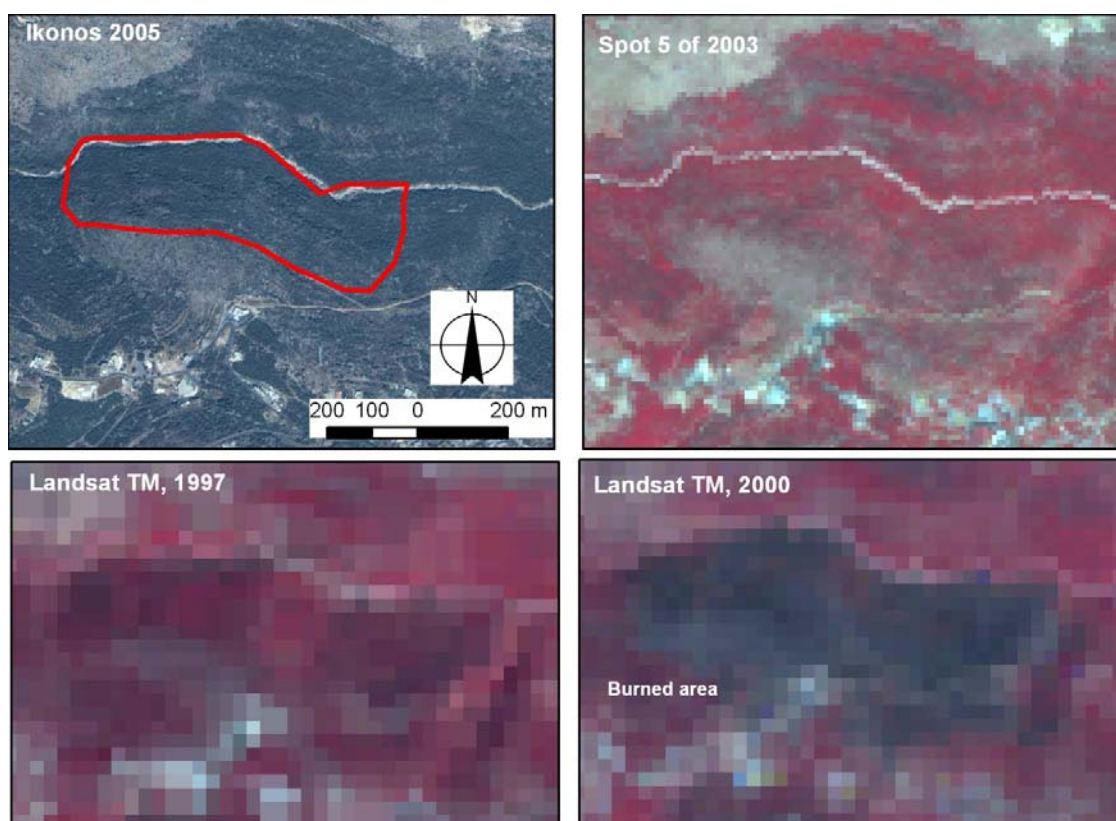


Figure 59. Oak forest regeneration in short period.

Since oaks are forests of the coastal and inner part of the study area, we compared NDVI values. The highest NDVI value (positive) at the inner land oaks was 60% less than the one obtained for closed (high cover density) oak forest from the coastal part. The difference in cover density is evident on the Ikonos satellite image of 2005 between oak forests on both sides of the study area (Figure 60).

MDVI was also tested and compared between both sides of the study area (inner side and coastal side), using Spot 5 satellite image of 2003. The highest NDVI value on the inner part of the area was 0.15 with standard deviation (STD) of 0.07. While, costal area showed an NDVI value of 0.5 and STD of 0.1. This comes in consistency with field observations where inner land forests appeared to have 15-30 m in between trees distance and coastal forests had 0.5-2 m trees distances.

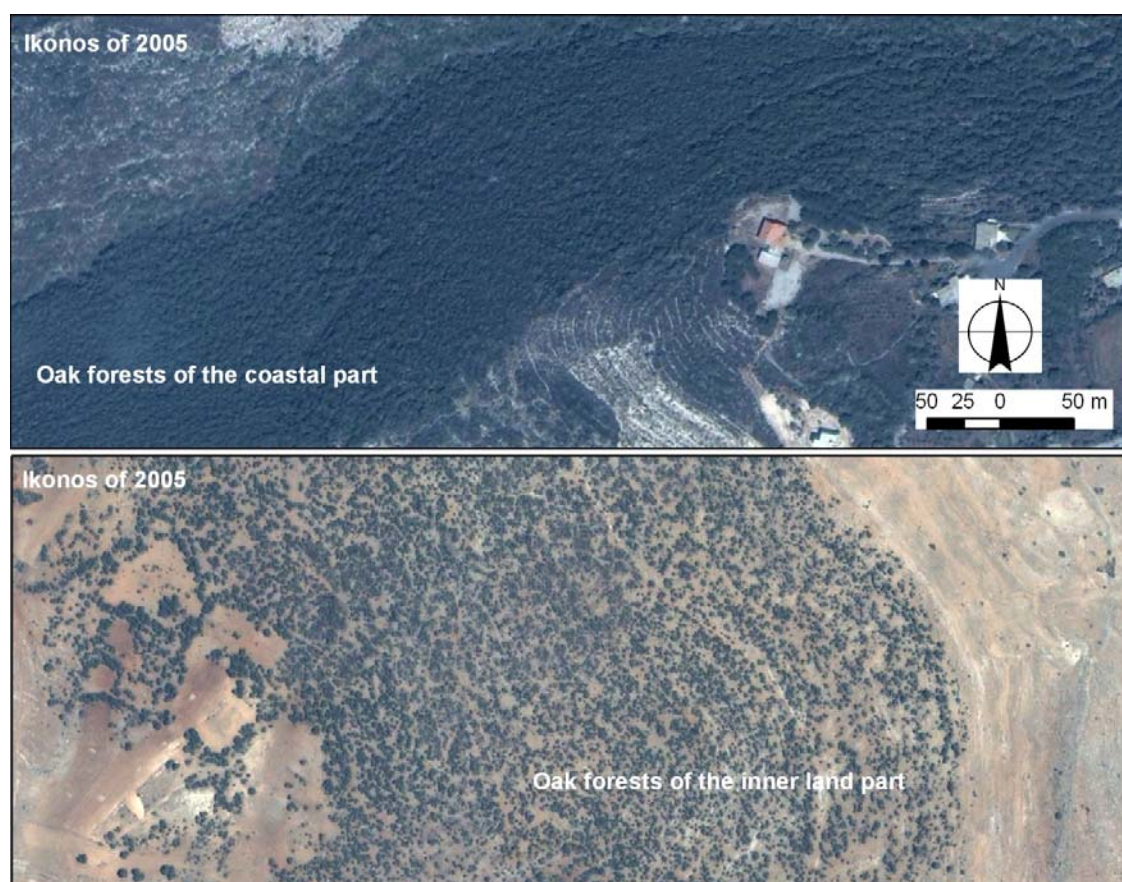


Figure 60. Oak forests of the highest density of cover on both parts of the study area.

2.10. Topographic analysis of forest patches

The forest patches complexity was calculated by counting the slope gradient faces per patch. This is what we called Relative Number of Topographic Faces (RTF). As described in the methodology a complex and topographically rugged forest-patch is the one with high RTF value.

The reason that lies behind developing this index is reflecting the topographic effect on forests of the study area, which is mountainous in habitat. The landscape indices at patch level uses only patch size and patch shape, which will not reflect the topographic complexity of the patches.

We tested this index on different forest patches of different criteria with regard to size and slope gradients. A forest patch with similar surface area was first chosen (38 ha). The

RTF has changed with degree of complexity of each patch from 1.0 to 1.2 and then to 1.7 when switching slope gradients faces number from 41, 48 and to 67.

The degree of complexity of the forest patches in the study area has ranged from 0.3 to 9.2 RTF value. Approximately 50% of the forest patches had topographic relative complexity between 1 and 2 (RTF) (Figure 61). For example, an RTF value of 1 means that a forest patch has for each hectare a different slope gradient.

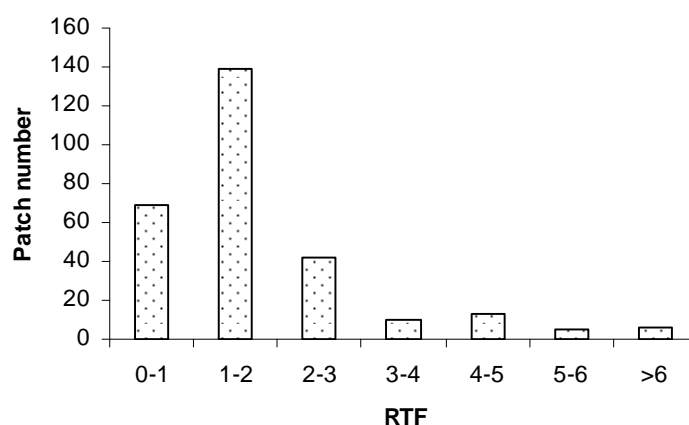


Figure 61. Topographic complexity of the forest patches in the study area.

We also checked the complexity of the topography with the Mean Nearest Neighbor Distance of the 1965 forest patches. This gave result to the fact that within 600 m MNN distance, there are more than 1000 times slope gradients of the following ranges: 0-10%, 10-20%, 20-30%, 30-40%, 40-50%, 50-60%, 60-70%, 70-80%, 80-90% and >100%. The range of 20-30% slope gradient is the most frequently (18% of total number of slope gradients) found within the MNN distance.

Part IV.

Discussions & Conclusions



Chapter 6

Discussion and conclusions

1. Discussions

The present research fits within the scope of landscape spatial analysis. This analysis is rarely applied or tested on Mediterranean environment. We introduced a methodology where landscape spatial indices could be applied and examined over forests of the Mediterranean. Forests of Lebanon were investigated for deforestation and. The results demonstrate how changes in spatial patterns of landscape could be assessed using spatial data of categorical and satellite image sources. Important new indices were invented and applied on the Lebanese landscape that they could be used in other areas of the Mediterranean.

1.1. Forests of Lebanon

In Lebanon, forests are found fragmented in relatively small patches (Jomaa *et al.*, 2008a). They are mainly mountainous in their behavior, since lower elevation areas have long history of exploitation. Spatial data representing forests need to enter monitoring like programs on the country level that standardize work and provide continuous information.

It was important to investigate changes of forest spatial patterns on coastal and inner lands of Lebanon. This partitioned analysis provided the difference of fragmentation processes that occur in each side, paving the road for better understanding of changes thus important help for possible future planning and management studies or programs.

Overall forest area in Lebanon has modestly changed between 1965 and 1998. However, forest annual decrease rate was noticeable for a small country like Lebanon that has limited forest resources. Although previous studies have demonstrated forest area decrease, this decrease was 6 times higher than what we have got in this research (Masri *et al.*, 2002). They actually used different data sources and with various spatial scale

precisely the forest map of 1966 on 1/200,000 scale and the landcover map of 1990 on 1/50,000 scale. Our base map was 1/50,000 spatial scale, i.e., the forest map of 1965. It should also be noted that the landcover map of 1998 had some problems in the forest delineations; this map also lack an accuracy statement with its accompanying documentation (Jansen and Di Gregorio, 2004).

It should be admitted that correction of the 1965 forest map for the entire country investigation was not performed. Our results concerning forest fragmentation for the entire country are, therefore, disputable. We did not perform entire country forest map correction because it should actually be performed in completely separate project that is only tackling this fact. This requires digitizing 121 topographic map of the country. It also require gathering aerial photos (might be enormous in number) for highly questionable locations. Field visits to remote areas might be necessary. In brief, we recommend having a research project to correct old forest spatial representation.

Coastal forests showed area increase, while inner land forests decreased dramatically. Thus, knowing the overall changes of a region alone will hide important spatial configurations. The overall estimate of the forest in Lebanon was until lately under debate where MoE estimated this to 7% in 1996 (Hamadi *et al.*, 1996) and in a newer study they reported a 13% forest cover (MoA and FAO, 2005b). Although it is known that the coastal part of Lebanon is highly humanized and it is facing larger urban expansion every day (MoE/LEDO, 2001), forest area increased. This requires further investigation, where a future study should investigate areas of changes that appear on previous maps (1965 forest and 1998 landcover maps) and on the ground all over Lebanon. We found that in some areas on the landcover map of 1998, riparian areas were delineated and considered as forests such as oaks in the coastal region.

The two forest types of the inland, i.e., oaks and junipers, showed important decrease in forest area. Junipers were largely affected by degradation, where grasslands have replaced 1/3 of the initial forest area (of 1965) by 1998. Junipers did not show important regeneration area as oaks. Although 80% of original oak area was replaced with grasslands, oaks has largely regenerated and demonstrated total area increase.

Consequently, computing the overall estimate of forest change is not sufficient and many spatial configuration characteristics will not appear and stay hidden. Although

overall forest area in Lebanon showed low decrease, forests had undergone important fragmentation phenomenon. Before this research, the 13% of forest cover did not change over the period from 1965 to 2005; data from the 1965 (refer to this research) and 2005 (MoA and FAO, 2005b) forest maps. The Mean Patch Size will alone change this trend and could explain how forests were degraded. Other computed landscape indices such as patch number on class and landscape level described the increase in isolation of forest patches on yearly basis. The decrease of Mean Nearest Neighbor index was related to aggregation of fragmented large patches into smaller size. Forest area appeared to be concentrated in small forest patches with time. Lebanon needs detailed study on forest spatial configurations monitoring, in order to bring clearer view to decision makers. Nevertheless, dividing the investigation between coastal and inner lands parts of Lebanon revealed important spatial forest analysis for management plans. As an example, we also used landscape indices in a manner to know the yearly rate of approximation of urban settlements with regard to forest patches.

Juniper and oak forests showed loss of 50% area inlands. This loss of area was accompanied with isolation and fragmentation of forest patches, which reflected a patch number increase and patch size decrease. Agriculture and grasslands are the major replacements that took over oak and juniper forests. Forests of Lebanon are mainly distributed on slope gradients up to 45%. Toward the coastal part, forests prefer Northwest slopping aspects; while inland forests are mainly located on southeastern slopes. Among the Mediterranean vegetation ensemble, oak forests appear to be mainly distributed on the supra-Mediterranean bioclimatic zone. Forest types are found in Lebanon with relation to abiotic factors. Distribution of forest types with regard to lithological formations and elevation was previously investigated (Abi Saleh, 1978). Since the abiotic-forest relation exists, if abiotic factors are found fragmented then forest would almost never be continuous and they will follow the preferable abiotics. For example, slope gradients, selected ranges of slope percentages, were found to be highly fragmented.

Forest patch spatial characteristics are usually considered a sign of ecological integrity. For example, large patches have more core area than small ones, which provide better environmental life conditions. Forest size, shape and edge density could not predict

future trends of forest changes. Forest area was lost or conserved in patches of sizes either large or small. Complex or simple shape forest patches did not relate to forest degradation or loss. We developed new patch characteristic, other than its size and edge shape. Although patch edge density together with its size provide an idea of the form, it will not clearly differentiate stripe like-shaped patches from others. The developed index was to differentiate patches with regard to their degree of elongations. We named the patch as patch-strip-like-shape (*Ps/s*). By knowing this patch characteristic, we also checked for possible relation of forest loss to such patch feature. It was found that approximately 40% of forests in Lebanon had a strip like shape of *Ps/s* above 0.6. Forest loss did not, however, show any relation to the form of the patch. Forest loss in Lebanon is highly related to artificial factors mainly, agricultural and urban expansion.

Since we computed the patch-stripe-like-index, we were able to have the orientation of each forest patch. Therefore, we calculated the mean patch orientation deviating from north (angle of 0° in the circle of direction from right, i.e., east, to left, i.e., west). Coastal patches had the southwest direction while inside forests are facing east. The overall orientation of the forests in Lebanon is southeastern.

1.2. Mapping forests in Lebanon

Forest spatial data in Lebanon goes back to the year 1962 with relation to the first aerial mission, i.e., the source of data. The first forest map was derived in 1965. Forest patch delineations were found doubtful after we investigated the study area. This fact should be known for future studies that use or rely on historical forest maps as main source of data, especially in Lebanon. It will be a duty to run through the accuracy of the data source, even if there were published. The amendments that we added on the 1965 forest map were critical for the purpose of this research, i.e., forest fragmentation and changes. The major encountered circumstances are places of missing forest patches on the produced map. The other situation was circling small patches that were considered un-mappable on 1/50,000 spatial scale, i.e., the map scale. However, these small forest patches were delineated and shown on same spatial scale map, i.e., the topographic map.

The rugged topographic characteristic was among the reasons of having such inaccurate forest patch delineations.

Remote sensing could help producing forest maps and with relatively high accuracy. Field investigations should remain supportive in mountainous topography of complex geomorphology such as Lebanon. High-resolution satellites have increased the accuracy of forest maps preparation. The acquisition date of the satellite image had affected their classification accuracy.

1.3. Forest pattern analysis

Oak forests area varied unpredictably with fragmentation and total forest area loss in the study area. These forests area increased during the entire period after it started with minor decrease between 1965 and 1972. The progressive increase of this forest type could be considered a sign of regeneration. This forest area increase was, at the same time, followed by replacement of 1965 oak areas with agriculture and grasslands. Rainwater harvesting reservoirs was also developed on oak forest area. Oak forests had some regenerated area to the outside forest locations of 1965. Since regenerated forest area of oaks was mainly in direct contact with original forests of 1965, these areas could be abandoned agricultural lands neighboring forest patches.

Juniper forests showed important decrease during the entire investigated period. By 1972, these forests were cut by half; where 70% of the forest area lost until the year 2003. It is evident that the majority of junipers area was degraded and changed to grasslands. However, the first period (1965-1972) loss of forest area could be related to the method of representing the forest patch as a homogeneous entity. We believe that forest area of junipers was over-increased because of encircling large area with gaps (opening within trees). Therefore, mapping juniper forests in Lebanon requires special care and it actually needs specific methodology.

Landscape pattern metrics provided a useful tool to explore forests at patch, class and landscape levels of details, which are considered as important ecological information for the investigated study area. The greatest forest area decline has coincided with the large decrease of forest patch size. Largest patch index and mean patch area decreased largely

between 1972 and 1989. At the study area, the majority of the forest area was found in patches of less than 10 ha in size. The path shape decreased its complexity during the studied period, which indicates changes in forest edges and probable artificial interference. Land use change to agriculture is the most factor change forest edge shapes. Proximity indices increased because of fragmentation of large forest patches into small aggregated ones. This is also indicated with decreasing mean nearest neighbor distance.

1.4. Forest regeneration

Forest regeneration is an analysis that should be taken into consideration while performing landscape analysis, especially fragmentation issues. Mediterranean forests such as oaks of the coast has high potential of fast emerging from fires, regenerate abandoned lands in relatively short period. Therefore, forest fragmentation might mislead the results especially with regard to indices related to patch number and area. Number of forest patches might increase and so fragmentation but it could be the result of regeneration or loss of forests in frequent fires.

Inside-outside patch analysis is a novel method of analyzing forest changes than provided by regenerated new forests. It is perfectly determined, in this research result, that forests of oaks at the coast require special treatment when performing landscape spatial analysis.

Regenerated forests demonstrated to have a certain degree of connectivity and dependence with regard to old existed forest patch. The applied distance analysis has determined forests that are far from originally forested areas. For other forest types, especially conifers, distance analysis has determined the reforested areas.

1.5. Hemerobiotic state of forest patches

Hemerobiotic of forest patches should be applied in Lebanon, since many factors are happening all-around or within forest patch. Forests are not isolated from human atmosphere. Roads cross forest patches in many places where in 1965 approximately 40% of the patches had roads inside. Roads increase forest fragmentation, as a forest

fragment should count two fragments (two patches). Roads increase, forest edges and decrease core areas. We believe that any future fragmentation study should consider roads as major fragmentation cause and enter them in configuration analysis.

As an indication of human influence on forest patches, we developed an index to calculate the road density inside the forest patches. This index proved to differentiate patches according to road length, crossing the patch. Road density index has ranged between 0 and 3.3. Although RD index seems low, any road crossing the forest will at least affect some processes. We advise this index to be computed in similar areas like Lebanon, having small sized forest patches and high road density.

We also checked forest loss if it relates to: (1) road presence and its length, and (2) distance to human settlements. Forest degradation did not correlate to either road presence or to human-forest distance.

High spatial resolution satellite images helped to detect linear feature inside forest patches other than roads. These linear features might be trails for human use or indirect effect of human interference within the forest patch or all around it. Excavation on top hill affects lower forest patch through eroded materials.

We also checked forest patch hemerobiotic state, investigating the patch edge form. Intrusions in forest patch edge were mainly the result of human influence by agriculture and settlements. Intrusions cause the appearance of dents-like forms of forests (gulf-like forest shape). Therefore, number of dents for a forest patch could be a sign of the patch hemerobiotic state.

1.6. NDVI in forest patches

NDVI could be used to detect fire events as an important factor of forest fragmentation in Lebanon. Fire could increase forest fragmentation for short or long period, depending on forest type. Fire cuts forest patches or changes their shapes. Oak forests were recovered to pre-fire NDVI value in couples of years time span. Therefore, changing in forest fragmentation might also be caused by natural events.

NDVI computation also helped to differentiate qualitative same forest types in different climatic conditions. Oak forests of inlands have approximately 60% less NDVI value than coastal oaks.

1.7. Topographic effect on fragmentation

The specificity of rugged topographical characteristics of Lebanon forced us to analyze this aspect in relation to forests. Previous studies has noted and worked to solve the effect on computing landscape indices while introducing altitudinal (Manhattan or Euclidean distances) values in distance computation (Dorner *et al.*, 2002). Their attempt was to correct the Mean nearest Neighbor index (MNN)

We developed an index that reflects the topographic complexity of a forest patch, which might overcome our need to correct for Euclidian distances. The slope gradient faces were counted within each forest patch to describe its topographic complexity in a new index that we called Relative Number of Topographic Faces (RTF). Based on this index (RTF), forests at the study area changed from more to less topographic complexity characteristics between the years 1965 and 2003.

Furthermore, Dorner *et al.* (2002) computed the MNN index after correcting the distance on projected maps to Euclidean distance. We, instead, calculated the number of topographic slope gradients within the MNN distance. The number of slope gradients within the MNN distances described the complexity of the connectivity between forest patches. Connecting the MNN index alone will not explain in a more realistic way the quality of the connectivity between forest patches. For example, a MNN of 10 m would be highly different in two areas that have different number of slope gradients; for example, a place has 10 m of MNN distance with 2 sloping faces, will be completely different than another place with same MNN distance (10 m) but of 20 sloping faces. In other words, a distance between forests of simple topographic characteristics will differ ecologically speaking than if this distance is largely complex topographically. The distance between forest patches is ecologically important to what is related to the ability of species to move from forest patch to another forest patch. Our attempt was to provide the quality of this distance (between forest patches), i.e., the connectivity quality from

topographic point of view. Ecologically the connectivity between forest patches might be high in less topographically complex distance.

1.8. Juniper forests mapping problem

In Lebanon, junipers forests are characterized by dispersed trees. This characteristic causes difficulty in forest spatial representation on maps. On the 1965 forest map, the juniper forest patches was drawn in subjective manner. These forest patches seems to be spatially exaggerate (large) in its area that amplified the total forest cover overall Lebanon especially in 1965. This spatial representation problem will negatively affect results of monitoring studies such as fragmentation analysis studies in this research.

We developed a new methodology that serves to overcome the problem related to spatial representation of juniper forests. This method will allow accurate monitoring of such forests. It also eliminates the extra area (salt and pepper) that is added to the each forest patch.

1.9. Other innovated landscape analyzing indices

Forests in Lebanon have special features that should be considered when performing fragmentation and landscape analysis. The complexity of topographic form of these forests was tackled alone as a natural physiographic feature (see paragraph 1.6. in this section). The topographic complexity analysis was found as an important new landscape analysis approach.

Another index was the *PsIs* (degree of relative patch strip-like shape) which could be found as a natural feature or it could be induced and caused through anthropic influences. The *PsIs* allowed introducing new index that is the orientation of a forest patch.

Hemerobiotic state of forest patches had several new ideas. Intrusions and dents hanging to a forest patch were counted because of their ecological importance (similar to corridor like patches (see results part related to hemerobiotic investigations). Another index is the road density in a forest patch, which indicated the degree of human pressure exerted on forests. Visual inspection for signs of human traces within forest patches was

Discussions and Conclusions

performed using high spatial resolution satellite images, as another part of hemerobiotic investigations.

2. General Conclusion

The major objective of this research is to investigate the majority of forest fragmentation in Lebanon in order to improve the understanding of forest dynamical changes, thus to increase the ability to construct better management plans. The simple expression “forest fragmentation” when investigated requires a judicious integration of several disciplines, mainly: the ecological knowledge, remote sensing data, and software capabilities.

This research ended up in quantifying the major changes in forest cover in Lebanon and assessing the substantial forest loss that has taken place over the last 40 years in a selected area of study. Remote sensing methods in conjunction with spatial pattern analysis were applied for the first time on forest studies of Lebanon. The conducted analysis illustrated how forest loss was associated with changes in pattern and fragmentation. The successful description of pattern change accompanying forest fragmentation provides a critical component of habitat analysis in the future. These changes may result in the elimination, displacement, or enhancement of species. Additionally, the identification of these changes was important to facilitate future landscape management and monitoring actions of forests. Devoted management with a focus on biodiversity conservation and sustainable uses is necessary. Although an analysis of the effects of fragmentation on the species level was not tackled in this research, the description of landscape spatial pattern provides a basis for future research investigating such impacts.

Human activities and environmental factors (mainly fire events at the coastal region) have influenced the dynamics of forest patches since the beginning of the studied period in 1965. In this research, which covered the period from 1965 to 2005, an obvious forest disturbance has appeared in 1965, mainly as roads crossing and fragmenting the forest patches. This fact has already influenced the number of patches from the beginning of the study period. Thus, fragmentation decreased the forest patch size and it may have further and even more severe consequences on compositional and other ecological characteristics. Throughout the study period, we observed a continuous trend of increase

in the number of patches in the study area. There was a corresponding decrease of mean patch size with an increase in the number of patches, indicating that fragmentation was continuing with time (non-stop process). The process of non-stop fragmentation proves that the Lebanese landscapes did not go through better management systems or the management did not significantly change through time.

The results obtained in this research revealed how the forest is being rapidly fragmented in landscapes around Lebanon. It is clear that care should be reinforced in managing forest resources. This research provided clear view on how forests are being fragmented not only by settlements, but also through construction processes, certainly roads of different size. In this view, road crossing through forest patches is a fact that receives no attention by managers. Negative ecological circumstances and fragmentation of natural resources are the result of such ignorance. The harm impact done to landscape in Lebanon through construction processes (e.g., roads, quarries, etc) is not yet fully realized. Thus, monitoring fragmentation must be implemented within the environmental institutions.

The coastal region of Lebanon is found to be more rapidly fragmented than the inland region. This diversity in the magnitude of fragmentation in different regions motivated us to select a pilot area that spans between both regions (i.e., coastal and inland regions). It was obvious that although fragmentation occurs in both regions, yet the coastal one is much more affected. This was attributed to the intensive human activities, and mainly road construction. The use of satellite images in this study explained how different zones have changed through time. The mean patch area showed continuous decrease at the coast, whereas it reached almost a steady state in-land.

Detailed forest analysis was possible using high spatial resolution satellite images; in this case, Ikonos images were utilized. The linear features inside forest patches were detected and were found to be influenced by human activities. Nevertheless, better delineation of juniper forests were performed also using Ikonos images.

Another major component of analysis, landscape indices provided valuable ecological information. Remote sensing constitutes a pertinent source of data for monitoring forest landscapes and offer important spatial data for detailed landscape spatial configuration

analysis, e.g., using landscape indices. Diachronic spatial information, obtained from remote sensing, are the core of forest fragmentation analysis.

Normally, landscapes of Lebanon are characterized by mountainous and rugged topography, which sometimes affect the interpretation of satellite image and though in computing landscape indices. These conditions require special treatments. Forests of Lebanon are highly fragmented, which also increase the difficulty of forest investigation, especially having accurate spatial forest representation. Accuracy of available spatial data has affected the obtained results.

Although, nowadays landscape indices are enormous in number, but they might not characterize fragmentation in special areas such as the Mediterranean forests and in particular forests of Lebanon. The topographic complexity should be considered as a part of landscape indices in such areas.

The major outcomes obtained in this research could be concluded as follows:

1. Forests of Lebanon should be sequentially investigated, especially to monitor changes in space and time, and in separate divisions between Mediterranean ensemble and Mediterranean presteppe vegetation zones. Combining the two parts of Lebanon in one landscape will negatively affect the procedure of fragmentation analysis and will cause false interpretation of landscape indices. These indices are better interpreted when computed separately. In addition, carefulness should be the case when introducing landscape indices to investigate forest changes in Lebanon.
2. Oak forests of the coastal part of Lebanon are the key player in changing results obtained for landscape indices, and on a short time basis. After fire events, rapid recovery, regeneration at abandoned agricultural lands, and re-sprouting after cutting, are major elements in this issue. Inside-outside forest patch analysis, is therefore considered essential for this forest type in the coastal region. Inner land oaks did not show such changing phenomenon.
3. Forests of Lebanon are oriented differently with regard to inner and coastal regions. This was an important ecological finding that requires further investigation. It is obviously known that forests of the coastal part are oriented southwest, while that of the inner lands are eastward oriented.

4. Forests of large continuous form are far from being found in Lebanon. Since the substrata (an abiotic factor) is preferable by forests are found fragmented in small sized patches.
5. Although the 1965 forest map of Lebanon is the most spatially detailed old source of data on forests, yet it is not perfectly useful for forest fragmentation analysis in its original situation. Amendments should be undertaken to increase its spatial forest delineation accuracy before utilization.
6. Linear features within forest patches are mainly the result of human interference through constructing roads and digging excavations among the forests. Roads in Lebanon are found in almost 1/3 of the forest patches of Lebanon. Therefore, road density is an important index required to be computed when analyzing forest fragmentation.
7. Intrusion against a forest patch is an important spatial feature in forests of Lebanon that must also be added to landscape analysis. Urban influence on forest edge causes intrusions into the forest, which in turn cause the appearance of dents or gulf-like forest forms. These are primary signs of fragmentation that and should be counted for forest patches. The characteristic of the intrusion is another factor that should be investigated such as abrupt or smooth like form.
8. The form of the forest patch is an important feature added on the characteristics of Lebanese forests. Since forests of Lebanon are found in strip like patch forms we developed an index to compute how elongated a patch is. This is called “strip-like patch shape index”
9. The topographic complexity of Lebanon could be entered in landscape analysis using the index that we developed in this research. The Relative Number of Topographic Faces (RTF) within a forest patch could characterize the topographic complexity of a forest fragment. In addition, counting the number of, e.g., slope gradient faces within the MNN distance characterize the quality of connectivity between forest patches.

10. The problem of mapping and representing juniper forests was solved. The developed methodology introduced accurate spatial representation of juniper forests in Lebanon, which open the road for better monitoring approaches.

3. Future perspective and recommendations

- Sensitivity analysis related to the scale issue of the maps could positively enhance the results of such research (landscape analysis).

- Landscape spatial analyses are priority in investigating forests of Lebanon. Decision makers' needs more ecologically related information on the forest landscape. It is not enough to have an overall estimate of forest cover change.

- Information about regeneration of oak forests along the coast of Lebanon is critically needed. This is also should be related to oak recovery after natural or artificial degradation events.

- Topographic complexity should be investigated for the possibility to of being introduced landscape analysis. The indices we developed to study the complexity of topography and fragmentation of abiotics requires further investigation in future studies.

- Linear features and roads inside forest patches are highly affecting integrity. It is recommended to develop methodologies to better understand their effect on the forests.

- The abrupt and smooth intrusions on a forest patch are also a good area of future researches.

- More benefit and information could be obtained from using NDVI in forest investigations. Same forest type, for example, is highly different in NDVI when moving from one climatic zone to another.

- Further analysis should be done for what we called calibration circle when delineating juniper forests. These forests in Lebanon require standardization of a methodology in their spatial representation.

- Future researches are introduced to extend the detailed analysis that we applied for a specific study area for the entire country. Similar application of indices and forest map corrections are desperately needed for better management plans of forests in Lebanon.

3.1. Research output (for the time being) (See Annex II)

The following output should not be considered the only ones that could be obtained from this research, many others could be developed:

- (1) [Jomaa I.](#), Auda Y., Khater C. 2007. Contribution to the characterizing of forest fragmentation on the eastern flank of Mount-Lebanon over 33 years. *Lebanese Science Journal*, 8 (2), 59-74.
- (2) [Jomaa I.](#), Auda Y., Abi Saleh B., Hamze M., Safi S. 2008. Landscape spatial dynamics over 38 years under natural and anthropogenic pressures in Mount Lebanon. *Landscape and Urban Planning*, 87, 67-75.
- (3) [Jomaa I.](#), Auda Y., Hamze M., Abi Saleh B., Safi S. Analysis of Eastern Mediterranean oak forests over the period 1965-2003 using landscape indices on a patch basis. *Landscape Research*, accepted for publication 2008.
- (4) [Jomaa I.](#) Nécessité d'harmonisation des données provenant de cartes forestières libanaises "anciennes". Could be submitted as a report to Lebanese Science Journal.

References

References

- Abdullah S.A., Nakagoshi N. 2007. Forest fragmentation and its correlation to human land use change in the state of Selangor, peninsular Malaysia. *Forest Ecology and Management*, 241, 39-48.
- Abi Saleh B. 1978. Etude phytosociologique, phytodynamique et écologique des peuplements sylvestres du Liban; signification bioclimatiques et essai de cartographie dynamique. Thèse –Docteur-Es-Sciences, Faculté des Sciences et Techniques St. Jérôme, Université de Droit, D'Economie et des Sciences, Aix-Marseille III.
- Abi Saleh B., Nasser N., Hanna R., Safi N., Safi S., Tohme H. 1996. Lebanon Country Study on Biological Diversity. Terrestrial Flora. Republic of Lebanon, Ministry of Agriculture (MoA) and United Nations Development Programme. Lebanon. Vol. 3.
- Abi Saleh B., Safi, S. 1995. Les ripisylves du Liban, écosystèmes fragiles. Actes du Colloque Scientifique BIO'MES (41-45).
- Abi Saleh B., Safi S. 1998. Carte de la végétation du Liban au 1/500 000 + Notice explicative. *Ecologia Mediterranea*, XIV (1/2), 123-142.
- Alig R.J., Lewis D.J., Swenson J.J. 2005. Is forest fragmentation driven by the spatial configuration of land quality? The case of western Oregon. *Forest Ecology and Management* 217, 266-274.
- Antolin M.F., Addicott J. F. 1991. Colonization, among shoot movement, and local population neighborhoods of two aphid species. *Oikos*, 61, 45-53.
- Avery T.E. 1977. Interpretation of aerial photographs. Third edition. In chapter 2. Orientation and study of aerial photographs. p. 35. USA, Library of Congress. pp. 392.
- Baltaxe R. 1966. Carte forestière du Liban au 1/2^{00.000e}. Lebanese Republic, Green Plan. Issued by the Forestry, Education, Training and Research Projects. UNDP, FAO.
- Baranga D. 2004. Forest fragmentation and primates' survival status in non-reserved forests of the 'Kampala area', Uganda. *African Journal of Ecology*, 42, 70-77.
- Barbero M., Quézel P. 1995. Desertification, desertisation, aridification in the Mediterranean region and global change. *Functioning of Natural and perturbed Ecosystems*, Edit. Lavoisier, 549-570.
- Basbous M., de Tarade R. 1955. Notes sur l'écologie du cèdre du Liban. Publs. Univ. Liban. Sect. Sci. nat. 1, 1-24.

- Baudry J.L. 1986. "The Apparatus: Metapsychological Approaches to the Impression of Reality in Cinema," in Philip Rosen (ed.), *Narrative, Apparatus, Ideology*, New York, Columbia University Press, pp. 299-318.
- Beals E.W. 1965. The remnant cedar forests of Lebanon. *J. Ecology*, 53, 679-694.
- Benediktsson J.A., Swain P. H., Erso O. K.y, Hong D. 1990. Neural Network Approaches Versus Statistical Methods in Classification of Multisource Remote Sensing Data. *Institute of Electrical and Electronics Engineers, Inc. (IEEE) Transactions on Geoscience and Remote Sensing* 28, 4, 540-551.
- Benson B.J., MacKenzie M.D. 1995. Effects of sensor spatial resolution on landscape structure parameters. *Landscape Ecology*, 10, 2, 113-120.
- Beir P., Noss R. 1998. Do habitat corridors provide connectivity? *Conservation Biology*, 12, 1241-1252.
- Bélanger L., Grenier M. 2002. Agriculture intensification and forest fragmentation in the St. Lawrence valley, Québec, Canada. *Landscape Ecology*, 17, 495-507.
- Bernstein R. 1983. Image geometry and rectification. Chapter 21 in *Manual of Remote Sensing*. Ed. R. N. Colwell. Falls Church, Virginia: American Society of Photogrammetry. pp. 873-922.
- Berque A. 1995. Les raison du paysage, de la Chine antique aux environnements de synthèse, Paris, Hazan, pp. 192.
- Bissonette J. A. 2003. Linking landscape patterns to biological reality. Pages 15-34 in Bissonette J. A., Storch I., (eds.), *Landscape Ecology and Resource Management: Linking Theory with Practice*. Island Press, Covelo CA, and Washington, D. C.
- Boentje J.P., Blinnikov M.S. 2007. Post-Soviet forest fragmentation and loss in the Green Belt around Moscow, Russia (1991-2001): a remote sensing perspective. *Landscape and Urban Planning*, 82, 208-221.
- Boone R.B., Galvin K.A.S., Lynn S.J. 2000. Generalizing El Nino effects upon Maasai livestock using hierarchical clusters of vegetation patterns. *Photogrammetric Engineering & Remote Sensing* 66, 6, 737-744.
- Bowen M.E., McAlpine C.A., House A.P.N., Smith G.C. 2007. Regrowth forests on abandoned agricultural land: A review of their habitat values for recovering forest fauna. *Biological Conservation*, 140, 273-296.
- Bunnell F.L., 1990. Reproduction of salal (*Gaultheria shallon*) under forest canopy. *Canadian Journal of Forest Resource*, 20, 91-100.

- Burel F., Baudry J. 2003. Landscape ecology: concepts, methods, and applications. Enfield, N.H., Science Publishers.
- CAL, 1971. Atlas Climatique du Liban, Tome 1. Service Météorologique, Ministère des Travaux publics et Transports, 45p.
- CAL, 1973. Atlas Climatique du Liban, Tome 1. Service Météorologique, Ministère des Travaux publics et Transports, 40p.
- CAL, 1982. Atlas Climatique du Liban, Tome II. Service Météorologique, Ministère des Travaux publics et Transports, 31p.
- Cardillo M., Macdonald D.W., Rushton S.P. 1999. Predicting mammal species richness and distributions: Testing the effectiveness of satellite-derived land cover data. *Landscape Ecology*, 14, 423-435.
- Casazza G., Barberis G., Minuto L. 2005. Ecological characteristics and rarity of endemic plants of the Italian Maritime Alps. *Biological Conservation*, 123, 361-371.
- Catry F.X., Catro R.F., Bugalho M.N., Lopes T., Silva J.S., Morera F. 2006. Effects of fire on tree survival and regeneration in a Mediterranean ecosystem. *Forest Ecology and Management*, 234S, S197.
- Cayuela L., Rey Benayas J.M., Echeverría C. 2006. Clearance and fragmentation of tropical montane forests in the Highlands of Chiapas, Mexico (1975-2000). *Forest Ecology and Management*, 226, 208-218.
- Chatelin Y., Riou G., (eds). 1986. *Milieux et paysages*. Paris, Masson.
- Chouchani B. 1972. Le Liban: Contribution a son Etude Climatique et Phytogeographique. Mémoire du Doctorat du 3ème Cycle. Université de Toulouse, France.
- Chouchani B., Khouzami A., Quezel P. 1974. A propos de quelques groupements forestiers du Liban. *Biol. Ecol. Med. Marseille*, 1, 63-77.
- Colby J.D. 1991. Topographic Normalization in Rugged Terrain. *Photogramm. Eng. Remote Sensing* 57 (5), 531-537.
- Collevatti R.G., Grattapaglia D., Hay J.D. 2001. Population genetic structure of the endangered tropical tree species *Caryocar brasiliense*, based on variability at microsatellite loci. *Molecular Ecology*, 10, 349-356.
- Coppin J., Jonckheere I., Nackaerts K., and Muys B. 2004. Digital change detection

- methods in ecosystem monitoring: A review. *International Journal of Remote Sensing*, 10, 1565-1596.
- Crowther R.E., Evans J. 1986. Coppice. Forestry Commission Leaflet, 2nd ed., vol. 83, London, 23 pp.
- DAGG. 1963. Cartes topographiques à l'échelle de 1/50,000. Direction des affaires géographiques et géodésiques.
- Dale V.H., Pearson S.M., Offerman H.L., O'Neill R.V. 1994. Relating patterns of land-use change to faunal biodiversity in the Central Amazon. *Conservation Biology*, 8, 4 1027-1036.
- Dar el Handassah, 1996. A national survey on quarrying in Lebanon. Report prepared to the Ministry of Environment (MoE), Lebanon.
- Darwish T., Khawlie M., Jomaa I., Abou Daher M., Awad M., Masri T., Shaban A., Faour G., Bou Kheir R., Abdallah C., Haddad T. 2006. Soil map of Lebanon, 1/50,000. National Council for Scientific Research, Lebanon. Monograph Series no. 4. pp. 367.
- Daubenmire R. 1959. A canopy-coverage method of vegetation analysis. *Northwest Scientist* 33, 43-64.
- Debinski D., Holt R. 2000. A survey and overview of habitat fragmentation experiments. *Conservation. Biology*, 14, 342-355.
- De Luis M., Raventós J., González-Hidalgo J.C. 2006. Post-fire vegetation succession in Mediterranean gorse shrublands. *Acta Ecologica*, 30, 54-61.
- Di Castri F. 1981. Mediterranean-type shrublands of the world. Chapter one. In: Di Castri F, Mooney HA (eds) *Ecosystems of the World 11. Mediterranean-type shrublands*. Elsevier Scientific Publishing Company, Amsterdam, pp 1-52.
- Dorner B., Lertzman K., Fall J. 2002. Landscape pattern in topographically complex landscapes: issues and techniques for analysis. *Landscape Ecology* 17, 729-743.
- Dubertret L. 1933. La carte géologique au millionième de la Syrie et du Liban. Rev. Géo. Phys. Géol. Dyn., 6, 4, 269-316.
- Dubertret L. 1953. Carte géologique de la Syrie et du Liban au 1/50,000^e. 21 feuilles avec notices explicatives. République Libanaise, Ministère des Travaux Publics. L'imprimerie Catholique, Beyrouth, pp. 66.
- Dubertret L. 1966. Liban et Syrie et bordure des Pays voisins :Notes Mem., Moyen Orient, 8, 251-358.

- Echeverria C., Coomesa D., Salas J., Rey-Benayas J.M., Lara A., Newton A. 2006. Rapid deforestation and fragmentation of Chilean Temperate Forests. *Biological conservation*, 130, 481-494.
- ECODIT and MoE/LEDO, 2001. Lebanon state of the environment report (SOER). Ministry of Environment Lebanon.
- El Hussein K., Baltaxe R. 1965. Forest map of Lebanon at 1/50,000 scale. Forestry Education, Training and Research Project, Green plan, Lebanon. United Nations Special Fund/FAO.
- Emberger L. 1933. Nouvelle contribution à l'étude de la classification des groupements végétaux. *Rev. Gén. Bot.*, 45, 473-486.
- ERDAS Field Guide™. 2003. *ERDAS Field Guide™*, 7th edition. Leica Geosystems. GIS & Mapping, LLC, Atlanta, Georgia.
- Eriksson I., Teketay D., Granström A. 2003. Response of plant communities to fire in an Acacia woodland and a dry Afromontane forest, southern Ethiopia. *Forest Ecology and Management*, 177, 39-50.
- Fahrig L. 2001. How much habitat is enough? *Biological conservation*, 100, 65-74.
- FAO. 1990. Landcover map of Lebanon at 1/50,000 scale. FAO.
- Farina A. 1998. Principles and Methods in Landscape Ecology. Chapman & Hall, London.
- Fassnacht K.S., Cohen W.B., Spies T.A. 2006. Key issues in making and using satellite-based maps in ecology: A primer. *Forest Ecology and Management*, 222, 167-181.
- Forman R.T.T., Deblinger R.D. 2000. The ecological road-effect zone of a Massachusetts (USA) suburban highway. *Conservation Biology*, 14, 36-46.
- Forman R.T.T., Galli A. E., Leck C. F. 1976. Forest size and avian diversity in New Jersey woodlots with some land-use implications. *Oecologia*, 26, 1-8.
- Forman R.T.T. 1997. Land mosaics: the ecology of landscapes and regions. *Cambridge University Press. Cambridge, UK*.
- Forman R.T.T., Godron M. 1981. Patches and structural components for a landscape ecology. *BioScience* 31:733-740.
- Forman R.T.T., Godron M. 1986. Landscape Ecology. JohnWiley and Sons, New York, NY.

- Foster D.R., Motzkin G., Slater B. 1998. Land-use history as long-term broad-scale disturbance: regional forest dynamics in central New England. *Ecosystems*, 1, 96-119.
- Franklin J., Woodcock C.E. 1997. Multiscale vegetation data for the mountains of southern California: spatial and categorical resolution. In Scale in remote sensing and GIS, Quattrochi D.A., Goodchild M.F., eds pp. 141-168.
- Froment A. 1987. L'écologie et le paysage. Notes de recherches de la Soc. Géogr. Liège, 8, 37-48.
- Fu B.J., Hu C.X., Chen L.D. 2006. Evaluating change in agricultural landscape pattern between 1980 and 2000 in the Loess hilly region of Ansai County, China. *Agriculture, Ecosystems and Environment*, 114, 387-396.
- Fuller D.O., (2001). Forest fragmentation in Loudoun County, Virginia, USA evaluated with multitemporal Landsat imagery. *Landscape Ecology*, 16, 627-642.
- García D., Quevedo M., Ramón Obeso J., Abajo A. 2005. Fragmentation patterns and protection of montane forest in cantabrian range (NW Spain). *Forest Ecology and Management*, 208, 29-43.
- Geneletti D. 2004. Using spatial indicators and value functions to assess ecosystem fragmentation caused by linear infrastructures. *International Journal of Applied Earth Observation and Geoinformation*, 5, 1-15.
- Gèze B. 1956. Carte de reconnaissance des sols du Liban au 1/200,000^e. République Libanaise, Ministère de l'Agriculture, Direction de l'Enseignement et la Vulgarisation, Station Agronomique Libano-Française. Notice Explicative, pp. 52.
- Gibson D.J., Collins S.L., Good R.E. 1988. Ecosystem fragmentation of oak-pine forest in the New Jersey Pinelands. *Forest Ecology and Management*, 25 (2), 105-122.
- Gigord L., Picot F., Skykoff J. 1999. effect of habitat fragmentation on *Dombeya acutangula* (Sterculiaceae), a native tree on La Réunion (Indian Ocean). *Biological Conservation*, 88, 43-51.
- Giordano G. 1956 (page 19). The Mediterranean region A world Geography of Forest Resources (Ed. By S. Haden-Guest, J.K. Wright and E.M. Teclaff) pp. 317-52 New York.
- Girard M.C., Girard C.M. 1999. Traitement des données de télédétection, Dunod, pp.529.
- Gustafson, E.J., 1998. Quantifying landscape spatial pattern: what is the state of the art? *Ecosystems*, 1, 143-156.

- Hakim B. 1985. Recherches hydrologiques et hydrochimiques sur quelques karst méditerranéennes: Liban, Syrie et Maroc. Publications de L'université Libanaise. Section des études géographiques, tome 2, pp. 701.
- Hamadi S., Khouzami M., Tohme G. 1996. Lebanon Country Study on Biological Diversity. Comprehensive Report, Ministry of Agriculture (MoA) and United Nations Development Programme. Lebanon. Vol. 9.
- Haila Y. 2002. A conceptual genealogy of fragmentation research: from island biogeography to landscape ecology. *Ecological applications*, 12, 321-334.
- Hansen M.J., Franklin S.E., Woudsma C.G., Peterson M. 2001. Caribou habitat mapping and fragmentation analysis using Landsat MSS, TM, and GIS data in the north Columbia Mountains, British Columbia. *Can. Remote Sens. Environ.* 77, 50-65.
- Hanski I. 1994. A practical model of metapopulation dynamics. *J. Anim. Ecol.*, 63, 151-162.
- Hartshorne R. 1939. The nature of geography. Washington, DC: Association of American Geographers. 29, 3-4, 173-658.
- Hill J.L., Curran P.J. 2005. Fragment shape and tree species composition in tropical: A landscape level investigation. *African Journal of Ecology*, 43, 35-43.
- Hodgson M. E., Shelley B.M. 1994. Removing the Topographic Effect in Remotely Sensed Imagery. *ERDAS Monitor*, 6 (1), 4-6.
- Hoersch B., Braun G., Schmidt U. 2002. Relation between landform and vegetation in alpine regions of Wallis, Switzerland. A multiscale remote sensing and GIS approach. *Comput. Env. Urban Systems*, 26, 113-139.
- Holmgren P., Thuresson T. 1998. Satellite remote sensing for forestry planning— a review. *Scan. J. For. Res.*, 13, 90-110.
- Huntly N. 1991. Herbivores and the dynamics of communities and ecosystems. *Annual Review of Ecology and Systematics*, 22, 477-503.
- Iverson L.R. 1988. Land-use changes in Illinois, USA: The influence of landscape attributes on current and historic land use. *Landscape Ecology* 2, 45-61.
- Iverson L.R., Prasad A., Schwartz M.W. 1999. Modeling potential future individual tree-species distributions in the eastern United States under a climate change scenario: a case study with *Pinus virginiana*. *Ecological Modelling* 115, 77-93.
- Jaber B. 1995. Water problems of Lebanon. National Congress on Water Strategic Studies Center. Beirut (in Arabic), pp. 67.

- Jalas J. 1955. Hemerobie und hemerochore Pflanzenarten. Ein terminologischer Reformversuch. *Acta Soc. Pro Fauna Flora Fenn.*, 72 (11), 1-15.
- Jansen J.M., Di Gregorio A. 2004. Obtaining land-use information from a remotely sensed land cover map: results from a case study in Lebanon. *International Journal of Applied Earth Observation and Geoinformation*, 5, 141-157.
- Jensen J.R. 1996. Introductory digital image processing: A remote sensing perspective, 2nd ed. Prentice-Hall, Englewood Cliffs, NJ, P.330.
- Jha C.S., Goparaju L., Tripathi A., Gharai B., Raghubanshi A.S., Singh J.S. 2005. Forest fragmentation and its impact on species diversity: an analysis using remote sensing and GIS. *Biology and Conservation*, 14, 1681-1698.
- Joliveau T. 1994. *La gestion paysagère de l'espace rural : questions, concepts, méthodes et outils*. Revue de Géographie de Lyon 69, 4, 325-334.
- Jomaa I., Auda Y., Abi Saleh B., Hamze M., Safi S. (2008a). Landscape spatial dynamics over 38 years under natural and anthropogenic pressures in Mount Lebanon. *Landscape and Urban Planning*, accepted for publication 2008.
- Jomaa I., Auda Y., Hamze M., Abi Saleh B., Safi S. (2008b) Analysis of Eastern Mediterranean oak forests over the period 1965-2003 using landscape indices on a patch basis. *Landscape Research*, accepted for publication 2008, in press.
- Jomaa I., Auda Y., Khater C. 2007. Contribution to the characterizing of forest fragmentation on the eastern flank of Mount-Lebanon over 33 years. *Lebanese Science Journal*, 8 (2), 59-74.
- Jomaa I., Bou Kheir R. 2003. Multitemporal unsupervised classification and NDVI to monitor land cover change in Lebanon. *Options Méditerranéennes, Série B* 46, 43-49
- Jones P.D., Hulme M., Briffa K.R., Jones C.G., 1996. Summer moisture availability over Europe in the Hadley centre general circulation model based on the Palmer drought severity index. *International Journal of Climatology* 16, 155-172
- Kebrom T., Hedlund L. 2000. Land cover changes between 1958 and 1986 in Kalu District, Southern Wello, Ethiopia. *Mountain research and development*, 20(1), 42-51.
- Khater C., Abboud M. 2007. Management plan for Tannourine Cedar Forest Nature Reserve. Integrated Pest management for Cedars Forest in the Mediterranean-MoE/AUB/GEF-UNEP Project, Lebanon.

- Khouzami M., Hayek A., Bassil M., Fortunat L. 1996. Biological diversity of Lebanon. Republic of Lebanon, Ministry of Agriculture (MoA) and United Nations Development Programme. Lebanon. Vol. 9.
- Kobler A., Adamic M. 2000. Identifying brown bear habitat by a combined GIS and machine learning method. *Ecological Modeling*, 135, 291-300.
- Kolasa J. 1989. Ecological systems in hierarchical perspective: breaks in community structure and other consequences. *Ecology*, 70, 36-47.
- Kotliar N.B., Wiens J.A. 1990. Multiple scales of patchiness and patch structure: a hierarchical framework for the study of heterogeneity. *Oikos* 59, 253-260.
- Kruger F. J., Mitchell D. J., Jarvis J. U. M. (eds), 1983. *Mediterranean-type ecosystems. The role of nutrients*. Springer-Verlag, Berlin.
- Krummel J.R., Gardner R.H., Sugihara G., O'Neill R.V., Coleman P.R. 1987. Landscape patterns in a disturbed environment. *Oikos* 48, 321-324.
- LaGro J. 1991. Assessing patch shape in landscape mosaics. *Photogrammetric Engineering and Remote Sensing*, 57, 3, 285-293.
- Laurance W.F., Laurance S.G., Delamonica P. 1998. Tropical forest fragmentation and greenhouse gas emissions. *Forest Ecology and Management* 110, 173-180.
- Laymon S.A., Reid J.A. 1986. Effects of grid-cell size on tests of a spotted owl HIS model. In Wildlife 2000. Modeling habitat relationships of terrestrial vertebrates, pp. 93-96. Edited by Verner J., Morrison M.L., Ralph C.J. The University of Wisconsin Press: Madison.
- Levin S.A., Paine R.T. 1974. Disturbance, patch formation, and community structure. *Proceedings of the National Academy of Sciences (USA)*, 71, 2744-2747.
- Li H., Wu J. 2004. Use and misuse of landscape indices. *Landscape ecology*, 19, 389-399.
- Lindenmayer D.B., Fischer J., Cunningham R.B. 2005. Native vegetation cover thresholds associated with species responses. *Biological Conservation*, 124, 311-316.
- Lioubimtseva, E., 2003. An evaluation of VEGETATION-1 imagery for broadscale landscape mapping of Russia: effects of resolution on landscape pattern. *Landscape and Urban Planning* 65 (4), 187-200.
- Lipshitz N., Biger G. 1990. Dominance of *Quercus calliprinos* (Kermes oak) and *Pistashia palaestina* (Terebinth) association in the Mediterranean territory of Israel in the past. *Journal of Vegetation Science*, 1, 67-70.

- Lopez Garcia M.J., Caselles V. 1991. Mapping burns and natural reforestation using Thematic Mapper data. *Geocarto Intl.* 1, 31-37.
- Lovejoy T.E., Bierregaard Jr. R.O., Rylands Jr A.B., Malcolm J.R., Quintela C.E., Harper L.H., Brown K.S., Powell A.H., Powell G.V.N., Schubart H.A.R., Hays M.B. 1986. Edge and Other Effects of Isolation on Amazon Forest Fragments. *Conservation Biology: the Science of Scarcity and Diversity*, Ed M. E. Soulé, 257-285. Sinauer Associates. Sunderland, Massachusetts.
- Lugo A. E., Helmer E. 2004. Emerging forests on abandoned land: Puerto Rico's new forests. *Forest Ecology and Management*, 190, 145-161.
- Masri T., Khawlie M., Faour G. 2002. Landcover change over the last 40 years in Lebanon. *Lebanese Science Journal* 3, 2: 17-28.
- Mathieu R., Freeman C., Aryal J. 2007. Mapping private gardens in urban areas using object-oriented techniques and very high-resolution satellite imagery. *Landscape and Urban Planning*, 81, 179-192.
- Matsushita B., Xu M., Fukushima T. 2006. Characterizing the changes in landscape structure in lake Kasumigaura Basin, Japan using a high-quality GIS dataset. *Landscape and Urban Planning*, 78, 241-250.
- Mazerolle M., Villard M-A. 1999. Patch characteristics and landscape context as predictors of species presence and abundance: a review. *Ecoscience* 6, 1, 117-124.
- McGarigal K., Marks B.J. 1995. FRAGSTATS: Spatial Pattern Analysis Program for Quantifying Landscape Structure. Forest Science Department, Oregon State University, Corvallis.
- McShea W.J., Koy K., Clements T., Johnson A., Vongkhamheng C., Aung M. 2005. Finding a needle in the haystack: Regional analysis of suitable Eld's deer (*Cervus eldi*) forest in Southeast Asia. *Biological Conservation*, 125, 101-111.
- Meentemeyer, V. and E.O. Box. 1987. Scale effects in landscape studies. Chapter 2, in: M. Goigel Turner (ed.): *Landscape heterogeneity and disturbance*. Springer-Verlag, NY.
- Mehner H., Cutler M., Fairbairn D., Thompson G., 2004. Remote sensing of upland vegetation: the potential of high spatial resolution satellite sensors. *Global ecology and biogeography*, vol 13, 359-369.
- Meyer M., Werth L. 1990. Satellite data: management panacea or potential problem. *J. Forestry* 88, 9, 10-13.

- Millington A.C., Velez-Liendo X.M., Bradley A.V. 2003. Scale dependence in multitemporal mapping of forest fragmentation in Bolivia: implications for explaining temporal trends in landscape ecology and applications to biodiversity conservation. *Photogrammetry & Remote Sensing*, 57, 289-299.
- Millward A.A., Piwowar J.M., and Howarth P.J. 2006. Time-series analysis of medium-resolution, multisensor satellite data for identifying landscape change. *Photogrammetric Engineering and Remote Sensing*. 72(6): 653–663.
- MoA. 2003. National Action Programme to Combat Desertification. Ministry of Agriculture, Lebanon. United Nations Convention to Combat Desertification. With technical support of GTZ-Germany.
- MoA and FAO. 2005a. National Forest and Tree Assessment and Inventory. Final report. Republic of Lebanon, Ministry of Agriculture (MoA), project TCP/LEB/2903. http://www.agriculture.gov.lb/Studies/Final_forest_%20Report1.htm
- MoA and FAO. 2005b. Forest map of Lebanon, 2005, digital. National Forest and Tree Assessment and Inventory. Final report. Republic of Lebanon, Ministry of Agriculture (MoA), project TCP/LEB/2903. http://www.agriculture.gov.lb/Studies/Final_forest_%20Report1.htm
- MOA/MoE. 2002. Landcover map of Lebanon for the year 1998 (MOS: Mode d'Occupation du Sol). Prepared by the Lebanese National Council for Scientific Research (CNRS)-Remote Sensing Center with the collaboration of IAURIF (Institut d'Aménagement et d'Urbanisme de la Région d'Ile de France). LEDO program, UNDP. Ministry of Agriculture and Ministry of Environment (Lebanon).
- MoE. 2001. State of the environment report, SOER, ECODIT., Ministry of Environment, Lebanon.
- MoE/LEDO, 2001. Lebanon State of the Environment Report (SOER). In Chapter 10: biodiversity and natural heritage. Page 153. Ministry of Environment/ECODIT, Lebanon.
- Moreira F., Duarte I., Catry F., Acácio V. 2007. Cork extraction as a key factor determining post-fire cork oak survival in a mountain region of southern Portugal. *Forest Ecology and Management*, 253, 30-37.
- Mouterde P. 1947. La végétation arborescente de pays du Levant. *Publication tech. Scient. Ec. fr. Ing.* Beyrouth, 13, 1-54.
- Mouterde P. 1966; 1970 and 1983. Nouvelle Flore du Liban et de la Syrie. Editions de L'imprimerie Catholique Beyrouth (uniquement pour le volume 1966); Dar el-Machreq, Beyrouth (pour les volumes 1970; 1983 et les trois volumes de l'Atlas 1966; 1970 et 1983).

- Muldavin E.H., P. Neville G., Harper. 2001. Indices of Grassland Biodiversity in the Chihuahuan Desert Ecoregion Derived from Remote Sensing. *Conservation Biology* 15, 4, 844-855.
- Nehmé M. 1977. Fleurs sauvage du Liban. Conseil National de la Recherche Scientifique, Beirut, Lebanon, pp. 240.
- Noirfalise A. 1988. Paysages. L'Europe de la Diversité. CCE Publ. EUR 11452, 130 p.
- Noss R.F., Csuti B. 1994. Habitat fragmentation. Pages 237-264 in G.K. Meffe and R.C. Carroll, eds. *Principles of Conservation Biology*. Sunderland, MA: Sinauer Associates.
- Olivia J., Colinas C. 2007. Decline of silver fir (*Abies alba* Mill.) stands in the Spanish Pyrenees: Role of management, historic dynamics and pathogens. *Forest Ecology and Management*, 252, 84-97.
- O'Neill R.V., Krummel J.R., Gardner R.H., Sugihara G., Jackson B., DeAngelis D.L., Milne B.T., Turner M.G., Zygmunt B., Christensen S.W., Dale V.H., Graham R.L. 1988. Indices of landscape pattern. *Landscape Ecology*, 1, 153-162.
- Openshaw S., Taylor P. 1979. A million or so correlation coefficients: three experiments on the modifiable area unit problem. In: Wrigley, N., Bennett, R. (Eds.), *Quantitative Geography: A British View*. Routledge and Kegan Paul, London, pp. 60-69.
- Openshaw S., Taylor P.J. 1981. The modifiable areal unit problem. In: Wrigley, N., Bennett, R.J. (Eds.), *Quantitative Geography: A British View*. Routledge and Kegan, London, pp. 60-70.
- Ozenda P. 2002. Perspectives pour une géobiologie des montagnes. Lausanne. Presses Polytechniques et Universitaires Romandes.
- Pabot H. 1959. La végétation sylvopastorale et son écologie. Rapport au gouvernement du Liban. FAO, Rapport 1126 Rome.
- Pacha M.J., Petit S. 2008. The effect of landscape structure and habitat quality on the occurrence of *Geranium sylvaticum* in fragmented hay meadows. *Agriculture Ecosystems and Environment*, 123, 81-87.
- Pahari K., Murai S. 1999. Modelling for prediction of global deforestation based on the growth of human population. *ISPRS Journal of Photogrammetry & Remote Sensing* 54, 317-324.
- Pascual-Hortal L., Saura S. 2007. Impact of spatial scale on the identification of critical habitat patches for the maintenance of landscape connectivity. *Landscape and Urban Planning*, 83, 176-186.

- Paton P.W.C. 1994. The Effect of Edge on Avian Nest Success: How Strong Is the Evidence? *Conservation Biology*, 8, 1, 17-26.
- Peguy C.1970. Précis de climatologie. Masson, Paris, pp. 468.
- Peterseil J., Wrбка T., Plutzer C., Schmitzberger I., Kiss A., Szerencsits E., Reiter K., Schneider W., Suppan F., Beissmann H. 2004. Evaluating the ecological sustainability of Austrian agricultural landscapes-the SINUS approach. *Land Use Policy* 21, 307-320.
- Peñuelas J., Gordon C., Llorens L., Nielsen T., Tietema A., Beier C., Bruna P., Emmett B., Estiarte M., Gorissen A., Williams D. 2004. Non-intrusive field experiments show different plant responses to warming and drought among sites, seasons and species in a North-South European gradient. *Ecosystem* 7, 598-612.
- Pinchemel Ph., Pinchemel G.1992. La face de la terre. Elément de géographie, Paris, Armand Colin, pp.519.
- Plassard J. 1971. Carte pluviométrique du Liban à l'échelle 1/200,000. Ministère des travaux publics. Direction Générale de l'Aviation Civile.
- Plieninger T. 2007. Compatibility of livestock grazing with stand regeneration in Mediterranean holm oak parklands. *Journal for Nature Conservation*, 15, 1-9.
- Pueyo Y., Alados C.L. 2007. Effects of fragmentation, abiotic factors and land use on vegetation recovery in a semi arid Mediterranean area. *Basic and Applied Ecology*, 8, 158-170.
- Quézel P. 1974. Les forêts du pourtour méditerranéen. Notes technique. MAB, 2, UNESCO, Paris.
- Quézel P. 1985. "Definition of the Mediterranean Region and the Origin of its Flora." In: C. GÓMEZ-CAMPO (Ed.). *Plant Conservation in the Mediterranean Area*. Dr. W. Junk Publishers, Dordrecht.
- Quézel P., Médail F. 2003. Ecologie et biogéographie des forêts du bassin méditerranéen. Editions scientifiques et médicales Elsevier SAS. pp. 571.
- Reed R.A., Johnson-Barnard J., Baker W.L. 1996. The contribution of roads to forest fragmentation in the Rocky Mountains. *Conservation Biology*, 10, 1098-1106.
- Reunanen P., Mönkkönen M., Nikula A. 2002. Habitat requirements of the Siberian flying squirrel in northern Finland: comparing field survey and remote sensing data. *Annales Zoologici Fennici*, 39, 7-20.

- Rey J. 1955. Carte Pluviométrique du Liban Rep. Lib. Ministère des Travaux Publics, Paris.
- Ricotta, C., Avena G., Palma A.D. 1999. Mapping and monitoring net primary productivity with AVHRR NDVI time-series: statistical equivalence of cumulative vegetation indices. *ISPRS Journal of Photogrammetry and Remote Sensing* 54, 5, 325-331.
- Riitters K.H., O'Neill R.V., Jones K.B. 1997. Assessing habitat suitability at multiple scales: a landscape-level approach. *Biological Conservation*, 81,191-202.
- Riitters K., Wickham J., Coulston J. 2004. Use of road maps in national assessments of forest fragmentation in the united states. *Ecology and Society* 9 (2), 13. online: URL: <http://www.ecologyandsociety.org/vol9/iss2/art13>
- Riitters K., Wickham J., O'Neil R.L, Jones B., Smith E. 2000. Global-scale patterns of forest fragmentation. *Conservation Ecology* 4(2), 3. Available online URL: <http://www.consecol.org/vol4/iss2/art3/>
- Risser P.G. 1999. Landscape ecology: does the science only need to change at the margin? Pages 3-10 in: J.M. Klopatek and R.H. Gardner, (eds.). *Landscape Ecological Analysis*. Springer-Verlag, New York.
- Romero R., Luque S. 2006. Habitat quality assessment using Weights-of-Evidence based GIS modelling: The case of *Picoides tridactylus* as keystone species indicator of the biodiversity value of the Finnish forest. *Ecological Modelling*, 196, 62-76.
- Roughgarden J. 1977. Patchiness in the spatial distribution of a population caused by stochastic fluctuations in resources. *Oikos*, 29:52-59. Runkle, J. R. 1982. Patterns of disturbance in some old-growth mesic forests of eastern North America. *Ecology*, 63, 1533-1546.
- Rudis V.A. 1995. Regional forest fragmentation effects on bottomland woodland community types and resource values. *Landscape Ecology*, 10, 291-307.
- Salleo S., Hamze M., Jomaa I., Pitt F., Nardini A. 2002. Differential drought resistance of two Mediterranean oaks growing in the Bekaa Valley (Lebanon), *Plant Biosystems*, 136 (1), 91-100.
- Sanlaville P. 1977. Etude géomorphologique de la région littorale du Liban. Publications de l'Université Libanaise. Section des Etudes géographiques, Beyrouth, tome 1, pp. 405.
- Santos T., Tellería J.L. 1994. Influence of forest fragmentation on seed consumption and dispersal of Spanish juniper *Juniperus thurifera*. *Biological Conservation*, 70 (2), 129-134.

- Santos T., Tellería J.L., Carbonell R. 2002. Bird conservation in fragmented Mediterranean forests of Spain: effects of geographical location, habitat and landscape degradation. *Biological Conservation*, 105, 113-125.
- Sarkar S., Margules C. 2002. Operationalizing biodiversity for conservation planning. *J. Biosci. (Suppl. 2)* 27 299–308.
- Sauer, Carl O. 1963. The morphology of landscape. In *Land and life: A selection from the writings of Carl Ortwin Sauer*, ed. John Leighly, 315–50. Berkeley: University of California Press.
- Saura S., Castro S. 2007. Scaling functions for landscape pattern metrics derived from remotely sensed data: Are their subpixel estimates really accurate? *ISPRS Journal of Photogrammetry and Remote Sensing*, 62, 201-216.
- Saunders S.S., Mislivets M.R., Chen J., Cleland D.T. 2002. Effects of roads on landscape structure within nested ecological units of northern Great Lakes region, USA. *Biological Conservation*, 103, 209-255.
- Scarascia-Magnozza G., Oswald H., Piuissi P., Radoglou K. 2000. Forests of the Mediterranean region: gaps in knowledge and research needs. *Forest Ecology and Management*, 132, 97-109.
- SDATL, 2003. Schéma directeur d'aménagement du territoire libanais, phase 1, thème : socio-économie, titre : Population résidente. Echelle, 1/750000. Conseil du Developement et de la Reconstruction, République Libanaise.
- Shannon C.E., Weaver W. 1964. *The Mathematical Theory of Communication* (University of Illinois Press, Urbana). (Originally published in 1949, this contains a reprint of Shannon's 1948 papers that appeared in the Bell System Technical Journal.).
- Schindler S., Poirazidis K., Wrבka T. 2007. Towards a core set of landscape metrics for biodiversity assessments: A case study from Dadia National Park, Greece. *Landscape and Urban Planning*, in press.
- Seifan M., Kadmon R. 2006. Indirect effects of cattle grazing on shrub spatial pattern in a Mediterranean scrub community. *Basic and Applied Ecology*, 6, 496-506.
- Shaban A. 2003. Etude de l'hydroéologie au Liban Occidental: Utilisation de la télédétection. Ph.D. dissertation. Bordeaux 1 Université. 202p.
- Shaw D.J.B., Oldfield J.D. 2007. Landscape Science: A Russian Geographical Tradition. *Annals of the Association of American Geographers*, 97, 1, 111-126.

- Simonettia J. A., Grezb A.A., Celis-Dieza J.L., Bustamantea R. O. 2007. Herbivory and seedling performance in a fragmented temperate forest of Chile. *Acta Oecologica*, in press.
- Southwood T.R.E. 1981. Bionomic strategies and population parameters. In: May, R.M. (Ed.), *Theoretical Ecology: Principals and Applications*, second ed. Blackwell Scientific Publications, Oxford, UK, pp. 30–52.
- Spence J. 2001. The new boreal forestry: adjusting timber management to accommodate biodiversity. *Trends in Ecology and Evolution*, 16, 591-593.
- Staus N., Strittholt J., Dellasala D., Robinson R. 2002. Rate and patterns of forest disturbance in the Klamath-siskiyou ecoregion, USA, between 1972 and 1992. *Landscape Ecology*, 17, 455-470.
- Steinhardt U., Herzog F., Lausch A., Miller E., Lehmann S. 1999. Hemeroby index for landscape monitoring and evaluation. –In: Pykh, Y.A. Hyatt, D.E. Lenz, R.J. (eds): *Environmental Indices-Sytem Analysis Approach*, Oxford. EOLSS Publ., pp. 237-254.
- Talhok S.N., Van Breugel P., Zurayk R., Al-Khatib A., Estephan J., Ghalayini A., Debian N., Lychaa D. 2005. Status and prospects for the conservation of remnant semi-natural carob *Ceratonia siliqua* L. populations in Lebanon. *Forest Ecology and Management*, 206, 49-59.
- Talhok S., Zurayk R., Khuri S. 2001. Conservation of the Coniferous Forests of Lebanon: past, present and future prospects. *Oryx*, 35, 206-215.
- Théry M. 2001. Forest light and its influence on habitat selection. *Landscape Ecology*, 153, 251-261.
- Thornthwaite C.W. 1948. An approach toward a rational classification of climate. *Geogr. Rev.*, 38, 55-94.
- Tinker D.B., Resor C.A.C., Beavais G.P. Kipmueller K.F., Fernandes C.I., Backer W.L. 1998. Watershed analysis of forest fragmentation by clearcuts and roads in a Wyoming forest. *Landscape Ecology*, 13, 149-165.
- Thirgood J.V. 1981. *Man and the Mediterranean Forest*. London, 193 pp
- Thoms M.C., Southwell M., McGinness H.M. 2005. Floodplain–river ecosystems: Fragmentation and water resources development. *Geomorphology*, 71, 126-138.
- Tinker D.B., Resor C.A.C., Beauvais G.P., Kipfmueller K.F. Fernades C.I., Baker W.L. 1998. Watershed analysis of forest fragmentation by clearcuts and roads in a Wyoming forest. *Landscape Ecology*, 13, 149-165.

- Tischendorf L. 2001. Can landscape indices predict ecological processes consistently? *Landscape Ecology* 16, 235-254.
- Tohmé G, Tohmé H. 2001. Recherches sur le statut actuel de la flore du Liban. *Lebanese Science Journal*, 2 (1): 3-15.
- Tohmé G., Tohmé H. 2002. A thousand and one flowers of Lebanon. Publications of the Lebanese University, Natural Sciences section, number 22. Beirut, Lebanon. pp 309.
- Tou J.T., Gonzalez R.C. 1974. Pattern Recognition Principles. Addison- Wesley Publishing Company, MA. Reading.
- Turner M.G., O'Neill R.V., Gardner R.H., Milne B.T. 1989. Effects of changing spatial scale on the analysis of landscape pattern. *Landscape Ecology* 3, 153–162.
- Turner I.M. 1996. Species loss in fragments of tropical rain forest: a review of the evidence. *Journal of Applied Ecology*, 33, 200-209.
- Verlaque R., Médail F., Quézel P., Babinot J.F. 1997. Endémisme végétal et paléogéographie dans le bassin méditerranéen. *Geobios*, mém. sp. 21, 159-166.
- Vicente-Serrano S.M., Cuadrat-Prats J.M., Romo A. 2006. Aridity influence on vegetation patterns in the middle Elbro Valley (Spain): Evaluation by means of AVHRR images and climate interpolation techniques. *Journal of Arid Environments*, 66, 353-375.
- Vink A.P.A. 1983. Landscape Ecology and Land Use. Longman, New York, pp.171.
- Vogiatzakis I.N., Mannion A.M., Griffiths G.H. 2006. Mediterranean ecosystems: problems and tools for conservation. *Progress in Physical Geography*, 30 (2), 175-200.
- Vogt P., Riitters K.H., Iwanowski M., Estregui C., Kozak J., Soille P. 2007. Mapping landscape corridors. *Ecological Indicators*, 7, 481-488.
- Ward K., Kromroy K., Juzwik J. 2007. Transformation of the oak forest spatial structure in the Minneapolis/St. Paul metropolitan area, Minnesota, USA over 7 years. *Landscape and Urban Planning* 81, 27-33.
- Watson M., Whittaker R., Dawson T. 2004. Habitat structure and proximity to forest edge affect the abundance and distribution of forest-dependent birds in tropical coastal forest of southern Madagascar. *Biological Conservation*, 120, 311-327.
- Weber E. 1983. La fin des terroirs. La modernisation de la France rurale (1870-1914). Paris, Fayard.

- White P.S., Pickett S.T.A.. 1985. Natural disturbance and patch dynamics: an introduction. In S. T. A. Pickett and P. S. White (eds.), *The Ecology of Natural Disturbance and Patch Dynamics*, pp. 3-13. Academic Press, San Diego.
- Whittaker, R. H., and S. A. Levin. 1977. The role of mosaic phenomena in natural communities. *Theor. Popul. Biol.*, 12:117-139.
- Whittaker R.H. 1967. Gradient analysis of vegetation. *Biol. Rev.* 42, 207-264.
- Wickham J.D., Riitters K.H., O'Neill R.V., Reckhow K.H., Wade T.G., Jones K.B. 2000. Land cover as a framework for assessing risk of water pollution. *Journal of the American Water Resources Association*, 36, 1417-1422.
- Wittenberg L., Malkinson D., Beeri O., Halutzy A., Tesler N. 2007. Spatial and temporal patterns of vegetation recovery following sequences of forest fires in a Mediterranean landscape, Mt. Carmel Israel. *Catena*, 71, 76-83.
- Xia Z.G., Clarke K.C. 1997. "Approaches of scaling geo-spatial data", in *Scale in Remote Sensing and GIS* Eds D A Quattrochi, M F Goodchild (CRC Lewis, Boca Raton, FL) pp. 309 -360.
- Zechmeister H.G., Moster D. 2001. The influence of agricultural land-use intensity on bryophyte species richness. *Biodiversity and Conservation*, 10, 1609-1625.
- Zohary M. 1961. On the oak species of the Middle East. *Bulletin Res. Coun. Is.*, D, 9-86.
- Zohary M. 1973. Geobotanical foundations of the Middle East. *Geobotanica Selecta*, III, 6, 14, 1-49.

Part V

Traduction

Française

Traduction française

Résumé

Les forêts du Liban présentent une grande richesse écologique pour les ressources qu'elles fournissent aux populations et un intérêt patrimonial incontestable au travers d'espèces emblématiques telle que le cèdre du Liban. Elles ont fait l'objet de nombreux travaux depuis le milieu du XIX^{ème} siècle. En particulier, des cartes forestières ont régulièrement été réalisées depuis 1965. Nous proposons de reprendre l'ensemble de ces données, de les compléter par des images satellites récentes puis de développer des outils susceptibles de caractériser l'évolution des forêts du Liban durant ces 50 dernières années.

Une analyse critique de l'ensemble des sources qui prend en compte leur mode de constitution a permis de constituer un référentiel géographique et sémantique commun pour comparer toutes les cartes. Le dessin des îlots forestiers de la carte de 1965 et sa légende sont réinterprétés. De même, la carte 1998 de MOA/MOE (2002) est rendue compatible avec notre nouvelle sémantique. Les différentes images satellites (MSS 1972, TM 1989, Spot5 2003) sont classées selon une thématique qui respecte la logique des précédentes cartes. Une vérité terrain approfondie comptant plus de 170 relevés permet de statuer sur les ambiguïtés d'interprétation de ces différentes sources. Cette démarche fournit une collection de couches intégrées dans un Système d'Information Géographique dont l'homogénéité sémantique assure leur analyse conjointe par les méthodes de l'écologie quantitative.

Modéliser les paysages aide à mieux comprendre l'évolution des forêts méditerranéennes du Liban. Plusieurs indices fondés sur la caractérisation de « patches » sont adaptés pour évaluer l'emprise du développement urbain, les processus de dégradation/régénération, l'impact des facteurs abiotiques (topographie, pédologie, ...), les pratiques agricoles, le rôle des routes ... sur la fragmentation des îlots forestiers. Le nombre moyen de patches

par unité de surface, le périmètre, le nombre moyen de voisins les plus proches, ... sont quelques-uns des indices utilisés pour décrire les paysages libanais.

Les forêts du Liban apparaissent clivées en deux grandes entités : la zone côtière et la zone intérieure. En zone côtière, les peuplements de chênes sont denses et présentent une bonne régénération durant la période étudiée tandis qu'en zone intérieure, ils témoignent d'une importante dégradation due à la création de carrières ou à un déboisement laissant la place à des cultures et à des espaces herbacés. Les forêts de Genévriers semblent fortement dégradées sur l'ensemble du territoire bien que leur type de formation arborée lâche permette mal de quantifier leur évolution. La disparition d'un patch de genévrier ou sa régénération peut être due à un artéfact méthodologique.

Pour la première fois, cette étude réalise la synthèse de données acquises sur les forêts du Liban durant plus d'un demi-siècle. Elle met en évidence de façon incontestable une forte dégradation de ces forêts depuis 1965. Cette dégradation opère par une fragmentation des massifs forestiers qui deviennent ainsi plus vulnérables. La seule exception à cette dynamique de dégradation est constituée par les peuplements côtiers de chêne dont la superficie s'est accrue par régénération naturelle.

Note : Les consignes de l'Ecole doctorale « Sciences de l'Univers de l'Environnement et de l'Espace » demandent que les parties « résumé, introduction et conclusion » des thèses rédigées en anglais soient traduites en français. Nous avons choisi de ne pas réaliser une simple traduction de la conclusion mais d'inclure quelques éléments des chapitres consacrés aux méthodes et résultats dans le souci de la rendre compréhensible pour un lecteur qui n'aurait pas accès à la version anglaise.

Introduction

La disparition des forêts est la première cause mondiale de diminution de la biodiversité. La fragmentation qui débute en créant des patches à partir d'une forêt continue (Turner, 1996), isole les habitats (Debinski and Holt, 2000 ; De Luis et *al.*, 2006), modifie les configurations spatiales des forêts (Bélanger and Grenier, 2002, Jha et al. 2005), met en danger les espèces (Collevatti et *al.* 2001), par conséquent, diminue la richesse spécifique (Gigord et *al.*, 1999) et déséquilibre les dynamiques de populations (Watson et *al.*, 2004). L'équilibre écologique qui repose sur une organisation spatiale des forêts (Cayuela et *al.* 2006) est rompu. L'étude de la fragmentation s'inscrit donc dans un cadre qui lie processus biologique et configuration spatiale des paysages.

Ces relations explicites entre fragmentation et biodiversité encouragent les scientifiques à développer des outils adaptés au suivi des forêts. Des indices de description des paysages forestiers et de la fragmentation permettent de quantifier les changements (O'Neil et al., 1988 ; MCGarigal and Marks, 1995 ; Riitters et *al.* 1997). Ils utilisent une information fournie par les images satellites et stockée dans les Systèmes d'Information Géographique (SIG) pour caractériser les modèles spatiaux d'organisation du paysage et leur suivi. Cette utilisation combinée de la télédétection, des SIG et de l'analyse du paysage offre aux décideurs, aux protecteurs de l'environnement et aux scientifiques la possibilité de prendre des décisions plus rapidement à partir de données factuelles fiables.

La couverture forestière moyenne des pays du Bassin méditerranéen est très hétérogène et varie de 0,07% pour l'Egypte à 41% pour le Portugal. Pour le Liban, MoA and FAO (2005a) estiment la couverture forestière à 13% de la superficie du pays. Une autre source, Abi Saleh et *al.* (1996) l'évalue à 8%. Ces différences de quantification du couvert forestier libanais soulignent les disparités des sources et des méthodes de calculs utilisées (Abi Saleh and Safi, 1988 ; MoA and FAO, 2005b). Quoiqu'il en soit, le Liban apparaît comme possédant la couverture forestière la plus dense de tous les pays du Bassin méditerranéen.

Comme beaucoup de pays dont l'histoire est riche d'événements, les forêts du Liban sont fortement fragmentées. Pabot (1959) explique, en s'appuyant sur plusieurs années de données collectées sur le terrain, que les causes de la dégradation de la végétation

naturelle du Liban et de ses environs est principalement due à la déforestation, au pâturage et à l'érosion. Actuellement, la santé des forêts du Liban est mal connue car les études ne s'appuient que sur un indice, la couverture forestière. Il est donc important de mener à bien une approche d'écologie du paysage qui prenne en compte la structure arborée. Cette démarche est indispensable au suivi des forêts, à leur protection, à leur aménagement et finalement à la préservation de la biodiversité (Schindler et *al.*, 2007).

Bien que les outils de modélisation numérique du paysage se soient développés à partir de 1980 (Krummel et *al.*, 1987 ; O'Neill et *al.* 1988), leurs applications aux paysages méditerranéens sont peu nombreuses. Ce constat s'explique, au Liban, par la grande variété des paysages observés, résultante de la complexité géologique, topographique et de l'influence millénaire de l'homme qui rend leur modélisation difficile.

La biodiversité des forêts du Liban est en danger. Leur dégradation, due en particulier à leur fragmentation, qui est liée à une combinaison de facteurs naturels et anthropiques ne laisse plus subsister qu'une forêt morcelée composée de patches résiduels. L'urbanisation anarchique et les pratiques agricoles ont aggravé l'épuisement des ressources naturelles (Talhouk et *al.* 2001). Les carrières concourent également à la fragmentation des forêts. 710 carrières sont exploitées sur le territoire libanais (Dar el Handassah, 1996). Cependant, toutes les études sur la biodiversité des forêts du Liban ne prennent pas en compte la fragmentation. Seules des cartes d'occupation du sol et des statistiques globales de couvert forestier sont produites (MoA and FAO, 2005a). Aujourd'hui, le degré élevé de dégradation de la forêt libanaise qui n'est souvent plus présente que sous forme de fragments distribués à différentes altitudes, nécessite de nouvelles études pour améliorer leur gestion. En particulier, décrire les modèles d'organisation spatiale doit être la priorité pour une exploitation durable de la forêt.

Le Liban est l'un des pays signataires de la convention sur la diversité (CBD) en 1994. Cette convention édicte plusieurs recommandations internationales pour lutter contre la perte de biodiversité. Les moyens à mettre en œuvre concernent essentiellement le suivi, l'analyse et la communication des changements qualitatifs et quantitatifs de l'occupation du sol. Dans ce cadre, les scientifiques doivent se poser les questions suivantes :

Possédons-nous les données adéquates pour le suivi de la biodiversité des forêts du Liban ? L'information spatiale sur les forêts libanaises concerne essentiellement des

cartes et des descriptions plus ponctuelles de la végétation. Une carte forestière du Liban a été éditée en 1965. Une carte d'occupation du sol a été réalisée en 2002, mais pour l'année 1998. Les données existent mais elles sont difficilement comparables en l'état car les objectifs des auteurs des cartes n'étant pas les mêmes, les objets identifiés et leur mode de représentation diffèrent entre les cartes. La pertinence de ces données doit donc être évaluée par rapport à notre problématique qui est liée à la fragmentation des forêts.

Les données spatiales existantes sont-elles exploitables pour des analyses écologiques dans la mesure où elles ont été recueillies par des forestiers ou des aménageurs ? L'intérêt de rassembler et comparer ces données réside dans la longueur de la période d'étude possible. La première carte forestière date de 1965. La dernière carte d'occupation du sol a été imprimée en 2002. Des études d'évolution du couvert forestier et de son mode d'organisation spatiale sont donc envisageables pour une période couvrant plus d'un demi-siècle.

Conclusion et Discussion

Ce travail constitue l'analyse la plus complète jamais réalisée sur la déforestation et la fragmentation des forêts conduite au Liban. Il montre comment l'évolution du couvert forestier peut être modélisée par des outils relevant de la description quantitative des paysages. Les données sont extraites de cartes forestières et d'images satellites dont l'ensemble couvre une période d'un demi-siècle. Les enseignements apportés par cette étude au plan méthodologique et au niveau thématique dépassent le cadre géographique du Liban et peuvent être profitables à d'autres régions du globe, en particulier du pourtour méditerranéen.

Problématique

Comparer des relevés cartographiques réguliers réalisés depuis le milieu de XX^{ième} siècle à des données actuelles issues de la télédétection spatiale offre la possibilité d'analyser les processus de dégradation de la forêt au cours des 50 dernières années. La fragmentation des forêts est une des causes majeure de la perte de biodiversité parce qu'elle isole les populations et rompt les équilibres écologiques. Mieux comprendre ses mécanismes et mieux identifier les éléments qui permettent à la forêt de recoloniser des espaces doit aider les aménageurs à améliorer la gestion de la forêt.

Notre approche est pluridisciplinaire. Elle demande de maîtriser les concepts écologiques, les aspects techniques de la cartographie, de la télédétection et de calculs statistiques spatialisés. Son caractère régressif qui s'appuie sur des cartes anciennes et des données très récentes extraites des images satellites impose également d'utiliser les techniques de critique des sources empruntées aux historiens.

Les données

La mission aérienne de 1962 fut à l'origine de la première carte forestière du Liban réalisée en 1965 par Baltaxe (1966). L'étude détaillée de cette carte révèle de nombreuses lacunes : les limites des patches se sont révélées imprécises lors d'une vérité terrain

établie en 2005. La comparaison à une carte topographique réalisée à partir de la même couverture aérienne en 1962 montre que de nombreux petits îlots forestiers n'ont pas été mentionnés. Ces imperfections s'expliquent par la résolution moyenne de la carte 1/50 000 qui est très inférieure aux autres sources de données.

Une carte d'occupation du sol produite en 1998 par MoA et MoE (2002) fournit une autre image de la couverture forestière à une échelle identique 1/50 000. Les difficultés de comparaison sont dues aux divergences de point de vue des auteurs. La carte forestière se limite à une description fine des forêts sous forme d'îlots. Les grands types de formation forestière (chêne, genévrier, cyprès, cèdre, ...) sont répertoriés. La carte d'occupation du sol traite de l'ensemble des thèmes rencontrés dont la diversité englobe l'urbain, les cultures, ... et les formations forestières selon une classification élaborée par la FAO.

Une analyse de la qualité géométrique des îlots forestiers prend en compte l'antériorité de la carte de 1962 par rapport à la carte de 1965, la spécialité des auteurs des différentes cartes, topographe pour la carte de 1962, forestier pour celle de 1965 et enfin géographe pour la carte de 1998 dans le but de construire une connaissance des formations végétales qui soit comparable pour l'ensemble des sources. Par exemple, les îlots de genévrier les plus petits ne sont pas représentés sur la carte de 1965 tandis qu'ils le sont sur la carte de 1962. Cette différence n'est pas liée à la disparition des ces îlots entre 1962 et 1965 mais au fait que les forestiers accordent peu de valeur à cette formation. Nous avons donc décidé de les réintroduire dans la carte de 1965 en reprenant l'information contenue dans la carte de 1962. Dans cette même logique, pour comparer les légendes des cartes de 1965 et de 1998, une analyse sémantique reposant sur une connaissance écologique a permis d'identifier les formations arborées communes aux deux cartes et de définir une nouvelle échelle de taux de couverture.

Pour compléter les cartes forestières et d'occupation du sol, des images satellites existantes (Landsat MSS 1972, Landsat TM1989) et acquises pour le projet (Spot5 2003) est extraite une information compatible avec celle des cartes. Une vérité terrain réalisée en 2003 porte sur 170 relevés qui enregistrent des données sur le sol, la pente et la composition floristique. Les données relatives à la forêt sont enregistrées selon la grille obtenue lors de l'analyse sémantique des cartes forestières et d'occupation du sol. Les classifications supervisées des images satellites associées aux données extraites des cartes

fournissent une information spatialisée décrite selon une codification thématique identique pour les dates suivantes : 1965, 1972, 1989, 1998 et 2003.

Les outils d'analyse du paysage

Étudier l'évolution de la couverture forestière exprimée en pourcentage de recouvrement du sol apporte une information importante sur la santé de la forêt mais elle ne fournit aucun renseignement sur la structure des formations arborées, en particulier sur la fragmentation de la forêt. Les processus de fragmentation sont cependant essentiels dans le fonctionnement des formations végétales. Certaines espèces ne peuvent pas se développer en dessous d'une certaine taille d'îlots forestiers. D'autres sont inféodées aux lisières. Une bonne gestion doit prendre en compte ces facteurs et préserver la diversité des types de formations végétales.

Les paysages du Liban sont marqués par un relief accentué ce qui complexifie l'analyse des images satellites, inféode les formations à des éléments topographiques et pédologiques qui rendent difficile l'identification des rôles respectifs des facteurs abiotiques, biologiques et anthropiques lors de la caractérisation du paysage. Même si c'est particulièrement difficile, nous avons cependant choisi de ne pas nous limiter à la seule étude de la composition du couvert forestier mais d'analyser l'évolution de la forêt sur des critères de structure.

L'approche utilisée qui s'appuie sur l'analogie entre les îlots forestiers et le concept de « patches » donne la possibilité d'utiliser et d'adapter de nombreux descripteurs de structure développés et intégrés dans des bibliothèques informatiques. Par exemple, Fragstat (McGarigal and Marks 1995) fournit des outils d'analyse résumant la structure du paysage sous forme d'indices. Pour décrire les formations forestières, nous avons utilisé plusieurs indices existants : le nombre de patches, la surface moyenne des patches, la surface du plus grand patch, la dimension fractale pondérée des patches, la distance moyenne entre les patches voisins, l'indice de diversité de Shannon, l'indice d'équitabilité, l'indice d'entremêlement et de juxtaposition, ... Nous avons également développé des indices adaptés à nos besoins, par exemple le nombre de nouveaux patches autour d'anciens patches pour étudier les processus de régénération, le rapport moyen des routes

à l'enveloppe des patches pour cerner l'effet des voies de communication sur le mitage des forêts, ...

L'interprétation de ces indices appelle à la plus grande prudence lors de la description des forêts du Liban car le couvert forestier est hétérogène. De plus, le caractère montagneux complexifie les relations spatiales. Pour en tenir compte, les indices ont été recalculés en ne prenant pas en compte les distances projetées sur la carte mais les distances plus proches de la réalité calculées à partir du modèle numérique de terrain. Cet important travail d'adaptation des indices apporte une approche nouvelle qui se concrétise par une interprétation plus complète des forêts du Liban.

Les forêts du Liban

Notre étude comprend deux grandes parties. La première concerne l'ensemble du territoire libanais. Elle met à profit l'analyse critique de la carte forestière de 1965 et la carte d'occupation du sol de 1998. La deuxième partie porte sur une zone circonscrite à un rectangle de 22 km en latitude par 60 km en longitude touchant la côte méditerranéenne et centrée sur la ville de Bcharré. Une vérité terrain, la réinterprétation de la carte forestière de 1965, la carte d'occupation du sol de 1998 et les images satellites construisent un ensemble de données très riches qui permet de dépasser les simples statistiques de couvert forestier et d'aborder les problématiques de structure.

L'ensemble du Liban

Nos travaux montrent que les statistiques globales sur la forêt ne présentent que peu de changements entre 1965 et 1998. La diminution de la superficie des forêts n'est que de 5,4% entre 1965 et 1998. Ce résultat ne confirme pas les travaux de Masri et *al.* (2002) qui attestaient d'une diminution 6 fois plus importante. Cette différence est liée à la difficulté de comparer des statistiques globales fournies par les organismes qui ont travaillé durant plus d'un demi-siècle sur les forêts du Liban. Hamadi et *al.* (1996) estiment la couverture forestière du Liban à 7%. Plus récemment, MoA et FAO (2005b) l'évaluent à 17%. Mais la carte d'occupation du sol de 1998 sur laquelle se fonde cette dernière estimation comptabilise la ripisylve comme une forêt alors que cette formation n'était pas prise en compte dans les statistiques précédentes. Une analyse critique de la

carte forestière de 1965 et de la carte d'occupation du sol de 1998 est donc nécessaire pour réinterpréter ces données et construire un référentiel géographique et thématique fiable.

De plus, d'un point de vue écologique, le territoire libanais doit être découpé en deux grandes zones : un ensemble côtier méditerranéen et un ensemble méditerranéen de pré-steppe situé à l'intérieur des terres. Les forêts qui colonisent ces deux ensembles présentent des caractéristiques de vigueur, de mode de répartition spatiale très différente. En 1965, la proportion de chêne est quasi équivalente dans la zone côtière (56%) et dans la zone intérieure (52%) tandis que les genévriers sont plus localisés dans la zone intérieure (44%) que dans la zone côtière (8%). Une partition de l'espace en deux entités avant toute analyse est donc indispensable pour donner du sens aux études d'évolution temporelle des modèles spatiaux.

En effet, les faibles évolutions de la couverture forestière attestées entre 1965 et 1998 ne doivent pas masquer les évolutions de structure des formations forestières qui sont extrêmement importantes. Les forêts de chêne se sont naturellement régénérées en zone côtière au cours de ces 50 dernières années pour couvrir un espace plus important en 1998 qu'en 1965 ! Au contraire, dans la zone interne ne subsiste que 52% des forêts de chêne présents en 1965, le restant est majoritairement devenu des prairies ou des cultures. Une partie est également mitée par des réservoirs de collecte d'eau. Cette dégradation n'est pas compensée par une régénération naturelle dans les zones attenantes aux forêts soumises à une déprise agricole.

Dans cette zone intérieure, les forêts de genévriers sont également fortement dégradées. 67% des zones couvertes par les genévriers sont remplacées par des champs ou des prairies. Cette dégradation induit des modifications dans la structure des formations que de simples statistiques sur les évolutions de couvert végétal ne suffisent pas à quantifier. Le rôle des facteurs abiotiques et anthropiques dans cette évolution doit être recherché.

Les forêts du Liban sont composées d'îlots dont la présence est liée aux caractéristiques topographiques et pédologiques. L'utilisation des SIG a permis de confirmer pour l'ensemble du territoire libanais la répartition des espèces forestières en fonction de la nature des sols telle que décrite par Abi Saleh (1978). Les forêts de chêne se développent de préférence sur les zones relativement plates de pente inférieure à 40% tandis que les

genévriers tolèrent des pentes plus importantes de l'ordre de 60%. Associé à la topographie régissant l'ensoleillement et la pente des versants, le sol est responsable du modèle initial de distribution des espèces végétales. La résultante est donnée par l'orientation des îlots forestiers, Sud Ouest dans la zone côtière et Est dans la zone intérieure. Cette dernière observation est nouvelle et elle mérite certainement de plus amples investigations au niveau de ses conséquences écologiques et de l'aménagement du territoire.

La zone d'étude

Réduire la zone d'étude à un rectangle de 20 km x 60 km permet de disposer d'une information temporelle plus complète intégrant en plus des cartes de 1965 et 1998, les images satellites de 1972, 1989 et 2003. Ces nouvelles données confirment les résultats obtenus pour l'ensemble du territoire libanais tout en affinant le suivi temporel grâce aux nouvelles dates. La dégradation de la forêt précédemment mise en évidence entre 1965 et 1998 a été particulièrement importante entre 1965 et 1972. Pour la zone d'étude, le couvert forestier a régressé de 4% par an entre 1965 et 1972, puis il est resté quasiment constant entre 1972 et 2003. Cette stabilité globale cache une forte variabilité entre les formations arborées. Entre 1972 et 2003, les forêts de chêne progressaient de 26% tandis que les formations à genévriers régressaient de 33%.

Se focaliser sur un espace géographique plus petit a également permis une réinterprétation plus poussée des cartes de 1965 et 1998. L'amélioration de la définition spatiale des patches ainsi obtenue facilite l'analyse du paysage par des méthodes quantitatives. Des indices sont calculés pour résumer l'agencement des îlots forestiers, encore appelés patches, pour plus de généralité. Chaque indice répond à une problématique et permet de progresser dans les mécanismes qui président aux changements forestiers.

La fragmentation par une subdivision des massifs forestiers fragilise les espaces boisés et déséquilibre l'ensemble de l'écosystème. Pour la mesurer, le nombre de patches et la taille moyenne des patches sont deux indices qui fournissent une information cohérente sur la fragmentation. Plus les patches sont nombreux et par conséquent de petite taille, plus la fragmentation est importante. Durant les cinquante années de l'étude, le nombre de

patches ne cesse d'augmenter régulièrement de 284 en 1965 à 1472 en 2003. Simultanément, la taille moyenne des patches diminue de 219 ha en 1965 à 81 ha en 2003. La diminution de la taille moyenne est particulièrement importante entre 1972 et 1989 où la taille moyenne du patch diminue de 209 à 104 ha. Bien que le taux de couverture forestier soit relativement stable entre 1972 et 2003, des bouleversements importants se produisent : les massifs forestiers préexistants en 1965 se morcellent et conjointement une recolonisation de nouveaux espaces principalement par des chênes localisée préférentiellement dans la zone côtière se développe. La conséquence pour les autres espèces végétales et même animales est difficile à cerner sans de plus amples études.

D'autres indices sont calculés pour tenter de mieux identifier les mécanismes de dégradation. La première idée est liée à la relation forme des patches / sensibilité à la dégradation. Plus un patch est allongé, plus ses frontières soumises à une potentielle exploitation sont grandes et plus il devrait être fragile. Mais le calcul de l'indice d'élongation montre que les patches ne sont pas plus fragiles que les patches massifs. Dans le même ordre d'idée, un patch dentelé témoigne d'une agression de la forêt par l'homme au travers d'une urbanisation ou de la création d'un espace agricole. Cette forme devrait faciliter la pénétration à l'intérieur de la forêt, son exploitation et son remplacement par un autre type d'occupation du sol. C'est donc en théorie également un caractère de vulnérabilité. Mais, les analyses n'ont pas permis de le démontrer. Les patches dentelés en 1965 ne montrent pas une augmentation de leur fragmentation en 2003 bien que ce caractère témoigne d'une colonisation des espaces boisés par l'agriculture ou l'urbanisation.

L'urbanisation est importante entre 1965 et 1998. Les espaces urbanisés ont doublés durant cette période pour occuper 63434 ha en 1998. Ces zones urbaines se sont rapprochées des patches forestiers à raison d'une progression de 12m/an de manière à ce que la distance moyenne qui sépare un habitat d'un patch de forêt passe de 608 m en 1962 à 260 m en 1998. L'analyse montre que les patches les plus près des zones urbanisées sont les plus petits sans cependant noter une aggravation de la fragmentation au cours de la période 1965-2003 étudiée.

D'autres facteurs liés aux agressions que subit la forêt devraient jouer. La perméabilité aux intrusions peut être un des facteurs de vulnérabilité à la dégradation. Les routes sont un facteur important de structuration du paysage. Sur la carte de 1965, 40% des îlots sont traversés par une route. Ces voies de communication morcellent les îlots, augmentent le nombre de patches, diminuent leur taille et augmentent la fragmentation. Nous avons développé un indice adapté à la caractérisation de la densité des routes à l'intérieur des patches. Les résultats ne montrent cependant pas de corrélation entre la densité des routes et la dégradation des forêts.

Le relief très accentué du Liban demande naturellement de rechercher les relations entre topographie et dégradation. Pour prendre en compte les effets de la topographie, Dorner *et al.* (2002) recommandent d'introduire une composante de la pente pour calculer les distances utilisées par les indices. Les indices recalculés ne montrent pas de différence marquante par rapport aux analyses précédentes. La topographie n'intervient donc pas en modifiant les distances entre les objets mais plutôt en introduisant une complexité supplémentaire. Pour la quantifier, un nouvel indice (Nombre relatif de faces topographiques) fondé sur le nombre de facettes générées par le gradient de pente à l'intérieur d'un patch démontre que les forêts dans la zone d'étude s'installent préférentiellement sur les zones de faible complexité topographique.

Perspectives et recommandations

- Disposer d'une description par des indices qui ne se limite pas à de simples taux de couverture spatiale d'une formation arborée est une priorité. Cette information est indispensable aux décideurs pour mener à bien les politiques de restauration/préservation des forêts du Liban.
- Dans ce contexte, mieux connaître les processus de régénération des formations de chêne, en particulier dans la zone côtière, est indispensable. Estimer les conséquences sur l'écosystème du remplacement de massifs forestiers de grande taille par un ensemble de petits îlots doit faire l'objet d'étude prenant en compte l'ensemble de la biodiversité végétale et animale.

- Les forêts de genévriers bien que plus arbustives ont beaucoup plus souffert au cours du temps et elles méritent une attention particulière. Leur type de couvert forestier très lâche et hétérogène demande de poursuivre l'analyse en développant une méthodologie adaptée permettant d'établir des cartes comparables issues des cartes forestières et construites à partir des images satellites. L'idée est de déplacer dans l'espace à cartographier un cercle dont le rayon est fonction de l'échelle de la carte. Si deux patches de genévrier sont situés à l'intérieur du cercle, ils sont reliés et considérés comme formant un seul patch. Cette procédure est reproduite de proche en proche. L'effet pointilliste d'une représentation qui consisterait à représenter individuellement chaque bosquet de genévrier est ainsi évité.
- Le rôle des routes qui traversent les forêts doit être mieux compris. De même, l'importance des intrusions sous forme d'habitat ou de culture doit être mieux établie dans la vie des forêts. Un certain degré de plasticité liée à une régénération naturelle peut tamponner les effets de ces agressions.

Travaux de l'auteur réalisés dans le cadre de cette thèse (Annexe II)

- (1) [Jomaa I.](#), Auda Y., Khater C. 2007. Contribution to the characterizing of forest fragmentation on the eastern flank of Mount-Lebanon over 33 years. *Lebanese Science Journal*, 8 (2), 59-74.
- (2) [Jomaa I.](#), Auda Y., Abi Saleh B., Hamze M., Safi S. 2008. Landscape spatial dynamics over 38 years under natural and anthropogenic pressures in Mount Lebanon. *Landscape and Urban Planning*, 87, 67-75.
- (3) [Jomaa I.](#), Auda Y., Hamze M., Abi Saleh B., Safi S. Analysis of Eastern Mediterranean oak forests over the period 1965-2003 using landscape indices on a patch basis. *Landscape Research*, accepted for publication 2008.
- (4) [Jomaa I.](#) Nécessité d'harmonisation des données provenant de cartes forestières libanaises "anciennes". Could be submitted as a report to Lebanese Science Journal.

Annex 1

1. Geology of the study area

Table a1 presents the stratigraphic columns of Lebanon.

Jurassic

The oldest lithological formations seen in Lebanon are Middle Jurassic. The massive Jurassic formation occurs essentially in the central part of *Mount Lebanon* and in the Central and southern *Anti Lebanon*. In the study area, the Middle and Upper Jurassic emerges as follows:

- Middle

Callovian (j4):

Oxfordian (j5):

- Upper

Kimmeridgian (j6): Massive, highly fissured dolomite grey, jointed and well karstified limestone and dolomitic limestone, interbedded with thin marly limestone, as well as frequent horizons of cherty modules.

Cretaceous

During the early cretaceous, Lebanon was covered by a series of swamps, rivers and deltas, which proved a widespread sequence of sands and shales. They contain good fossil amber with well preserved insects.

The Cretaceous rocks represent the largest part of Mount Lebanon a constituting approximately 60% of the study area. These rocks are characterized by hard, massive and thick-bedded stratum, which are well karstified and fractured. Thus, argillaceous lithologies are also exist, especially the marl rocks. They represent soft, bedded rocks with tremendous erosion criteria. While a unique clastic rock formation (sandstone) is developed in the mountainous region. It is almost mixed with clayey material, where mass movement is plenty. Diversity of these rock types governs the distribution of several physiographic features, e.g., vegetation cover, water resources, etc. Table 3 summarizes the rock succession exists in the study area as attributed to several authors (Dubertret, 1953). The Cretaceous succession in the study area is as follows:

Table a1. Stratigraphic columns of Lebanon.

| <i>Era</i> | <i>Period</i> | <i>Epoch</i> | | <i>Lithology</i> | | <i>Thick- ness (m)</i> | <i>Spatial extent (km²)</i> | <i>% from total area</i> |
|------------|---------------|---------------------|--------------------------------------|----------------------|---|----------------------------|--|------------------------------|
| Cenozoic | Quaternary | | | <i>qaa</i> | Ancient Alluvial | variable | 32.2 | 1.7 |
| | | | | <i>a</i> | Arable land | | 18.9 | 1 |
| | | | | <i>qd</i> | Arable land and landslides | | 3.8 | 0.2 |
| | | | | <i>cp</i> | Colluvials | | 36.0 | 1.9 |
| | Neogene | <i>Pliocene</i> | | <i>p</i> | marl | 360 | 1.9 | 0.1 |
| | | <i>Mio-Pliocene</i> | | <i>ncg</i> | Continental deposits | | 303.2 | 16 |
| | | <i>Miocene</i> | | <i>m2</i> | pouding | 400 | 37.9 | 2 |
| | Cretaceous | <i>Upper</i> | <i>Senonian</i> | <i>c₆</i> | Chalky marl | 400 | 77.7 | 4.1 |
| | | <i>Middle</i> | <i>Turonian</i> | <i>c₅</i> | Marly limestone | 200 | 89 | 4.7 |
| | | | <i>Cenomanian</i> | <i>c₄</i> | Limestone, dolomitic limestone, marly limestone | 700 | 1114.3 | 58.8 |
| | | | <i>Albian</i> | <i>c₃</i> | Marly limestone, marl | 200 | 7.6 | 0.4 |
| | | <i>Lower</i> | <i>Aptian</i> | <i>c₂</i> | Clayey sandstone oolitic | 300 | 32.2 | 1.7 |
| | | | <i>Neocomian-Barremian</i> | <i>c₁</i> | Quartz sandstone, beds or clayey gray | | 3.8 | 0.2 |
| | | | <i>Basalt of Neocomian-Barremian</i> | <i>bc</i> | Bazalt interstratified | | 43.6 | 2.3 |
| Mesozoic | Jurassic | <i>Upper</i> | <i>Portlandian</i> | <i>j₇</i> | Oolitic calcareous | 180 | 89.1 | 4.7 |
| | | | <i>Kimmeridgian</i> | <i>j₆</i> | Dolomite, gray calcareous | 200 | | |
| | | <i>Middle</i> | <i>Oxfordian</i> | <i>j₅</i> | Volcanic materials, marly calcareous | 75 | | |
| | | | <i>Callovian</i> | <i>j₄</i> | Dolomitic calcareous, calcareous | 650 | | |

- Lower Cretaceous

Neocomian-Barremian (c1): The *Necomian-Barremian (C1)* consists of quartzitic and calcareous sandstone with interactions of siltstone and lignitic clays, interbedded locally with shales and sandy limestone. Tuffs sometimes appear among this formation, while some basaltic intrusions appear marking the boundary between the Jurassic and the Cretaceous.

Aptian (c2): Moderately thick-bedded clastic limestone interbedded with marl, argillaceous and sandy limestone, and shales.

- Middle Cretaceous

Albian (c3): Moderately thick-bedded of green marl (containing glauconite in some instances) intercalated with thick layers of marly limestone forming cliffs 3-4m in height. Thin bedded marly limestone and shales grading towards the top into moderately thick-bedded limestone, interbedded limestone, interbedded with marl.

Cenomanian (c4): Massive to thin bedded, highly fractured, jointed, chertified and well karstified dolomitic limestone and limestone with some thin beds of marly limestone.

- Upper

Turonian (c5): Moderately thick to thin bedded marly limestone with chert nodules. Distinguished by fossils otherwise joined with *Cenomanian (C4)*.

Senonian (c6): Marl and marly limestone, changing from massive, jointed, fractured to soft and friable in some localities. Cretaceous and lower Tertiary sediments indistinguishable lithologically. It is stiff bluish plastic marl with glauconite, interbedded with chalky marly limestone and nodules of black chert.

Tertiary

The mountain chains *Mount Lebanon* and *Anti Lebanon* start emerging at the end of the Cretaceous and tertiary sediments are distributed near these blocks.

Lutetian (e): Moderately thick to thin bedded, highly fractured and jointed, partly karstified bed of *Nummulitic* limestone with chert nodules, interbedded with marly limestone. The *Lutetian* of Anti-Lebanon does not seem to appear on the surface as on the Mount-Lebanon. The thicker bed of *Lutetien* (7 to 8 cm of diameter) is found at the eastern slope of Mount Lebanon.

Neogene: The Bekaa valley is covered by the torrential conglomerates. On the slopes of Anti-Lebanon the *Neogene* is less rectified of the Mount-Lebanon one. The *Neogene* comprises:

-*Miocene (m2)*: Conglomerate and sand, especially south of the study area. It is massive friable marly limestone and marl with silt marl in many instances.

-*Mio-Pliocene (ncg)*: North of the Bekaa, they are the conglomerates and the limestone they attain 500-600 m of thickness and appear in different places. The mixture of

conglomerates of *Ponto-Pliocene (Mio-Pliocene)* and the quaternary enclose a very important source of water (El-Assi river).

-*Pliocene (p)*: Conglomerate, sandstone and sandy marine marl, bluish in color.

Quaternary

The deposits of *Quaternary* are composed of alluvial deposits (qaa), and a cone of depression (cp) eroding from Jabal El-Maitri at the Yammouneh–depressions, which is filled by recent alluvial. There are also landslides (*qd*) found in various places of Mount-Lebanon located in the slopes under the *Cenomanian*. Mixed with clay, the landslide moves downhill composing a terrain of *Quaternary* characteristics. Arable lands (a) are of alluvial, fluvial and colluvial or mixed origin.

2. Soils of the study area

Soils at the study area will be determined according to the soil map at 1/200000 scale (Gèze, 1956b) (Figure a2). Soil was classified in this map based on the parent material type and the soil color. Therefore, one could easily notice the consistency or coincidence between this soil map and the geological map of Dubertret (1953). The soil color is influenced by the chemical compositions of soil with relation to the climate. Different chemical elements might migrate or are retained in the soil depending on the climate.

Soil classification using the color is not accurate as same colored soil might be different. Therefore, Gèze (1956a) asks for more detailed study that considers the physical and chemical constituents of the soil, if agricultural planning and management have to be performed.

The different characteristics of the soil types designated at the study area are classified below:

Soils on calcareous parent materials

- Red Soils (terra rossa) (11 and 12)²

These soils characterize the Mediterranean soil types. They are mainly spread at sub-humid and humid climate and at the litorale zones. The fact of their origin is still discussed in literatures.

They represent around 36% of study area with almost 20% at the littoral, 10% on the eastern slope of *Mount Lebanon* and the other distributed equally between the *Bekaa plain* and *Anti Lebanon*. It could be found up to an altitude of 2000 m. These soils are located between rocks and considered as discontinuous. They are formed in their place between the rocks. They are also found anchored within rocks of compacted calcium carbonate, in depressions and Karstic areas on Cretaceous or Jurassic. Rock formations, however, there are other places where these soils was carried with the slopes as colluvials to valleys and plains. Therefore, they are at the piedmont with considerable depth and used for different cultivation practices.

² (12) is used for continuous areas while (11) used for discontinuous red soils of rocks on the map.

From the physico-chemical characteristics, the red soils are seriously decalcified with only 0 to 6% CaCO_3 . The soil solution reaction stays close to neutral with pH values between 6.7 and 7. The clay content ranges from 30 to 50%. Analysis of the clay particles demonstrates the presence of a higher proportion of iron oxides (13 to 18% Fe_2O_3) that explains their red color. The percentage of aluminum to silicium is considerably lower with ratio of $\text{SiO}_2/\text{Al}_2\text{O}_3$, varying between 1 and 2. Available nutrients are from 1 to 2‰ for N, 0.2‰ for P_2O_5 and 0.1‰ for K_2O . The C/N ration varies between 12 and 14.

On such soil all types of vegetations could be grown depending on the climate: almonds and fig fruits in dry areas; olives and vines in mild zones; cereals and tobacco in irrigated places; field crops, bananas, and citrus where high water availability and warm weather exist. The main disadvantage is their discontinuity in the presence of calcareous rocks. This does not favor easy and cheap agricultural practices. Red soils are found continuous in the central Bekaa and SE of Tripoli at the coast. Other than that they are located in a number of valleys and plains of minor importance.

- *Yellowish mountainous soils (14 and 16)*³

They constitute around 20% of the study area. They could be found only in places where snow stays for several months during the year. Even with similar parent rocks, the red soils change progressively with altitude into soils of yellowish color. They were mainly detected on the *Cenomanian (C4)* rocks.

The percentage of large particles of stones and gravels is relatively high due to the disintegration of rocks under ice effect. Clay content is low to moderate changing between 20 and 40%. The decalcification is never complete, leaving low level of CaCO_3 (3 to 10%). The soil reaction is mostly slightly acidic (pH between 6.4 and 7), with exceptions of alkaline conditions (pH 7 to 7.6) in places where soil approaches the brown color under woods. The clay particles enclose little bit less iron (10 to 13% of Fe_2O_3), which produces a yellowish tint instead of red one. Furthermore, the ratio of $\text{SiO}_2/\text{Al}_2\text{O}_3$ is a bit higher than that of the red soil (described below). The presence of nutrients and organic matter varies a great deal. Sometimes the C/N ratio ranges between 13 to 18.

³ (14) is designated for places with discontinuous patches of such soils between rocks. (16) is assigned for depressions.

On such soil, the forest cover consists of cedar, oak and junipers on Mount Lebanon and only oaks for Anti-Lebanon. At high altitudes (2200m), Gèze in the fifties noticed that Anti Lebanon crops (wheat) are cultivated. However, the normal land cover of such soils should consist of woods due to the fact that these soils are mostly discontinuous and in elevated areas of the mountains.

- Brown soils (13)

They formed at high altitudes as the red soils. They are actually very similar to the red soil especially in the lower horizons. Clay content is high and reaches 75% in some places. The total CaCO_3 goes higher than red soils but stays between 4 and 10%. In the lower horizons the total CaCO_3 might be little higher and reach 20%. The pH is alkaline ranging from 7 to 7.6. The clay contents of iron oxides are similar to the red soils. The only deficient nutrient is the phosphoric acid. The C/N ration is always relatively high and moves from 13 to 25%, which means the mineralization of humus is slow. They are found with less than 1% cover in the area.

Steppic and sub desertic soils

- Steppic light chestnut soils (38 and 39)⁴

They are found at places with an average rainfall of 450 to 600mm. They are originally formed from the red soils of the mountains that reach the piedmont and change to light chestnut color with lower clay content and high presence of gravel. With places of lower rainfall rate (North of the Bekaa plain) these soils becomes lighter in color. They form around 8% of the study area.

The characteristics of the clay particles do not differ from red soils. However, they differ with the presence of very little organic matter, higher active CaCO_3 content and alkaline pH (7.4 to 7.6).

These types of soil could support agriculture similar in many situations to red soils. However, toward the Northern Bekaa the calcic layer became shallow, which caused high soil water erosion leaving the soil hard to be rehabilitated.

⁴ (38) are discontinuous while (39) continuous soils.

- *Subdesertic yellowish soils (40 and 41)*⁵

They are located in the north of the Bekaa and Anti-Lebanon where the average rainfall drops below 300 mm year and does not reach in most of the cases the 200 mm year. They make almost 9% of the study area. Soils are yellowish to whitish in color, characterized by very high content of silt (40% or higher). Clay content is as low as 4 to 11% and sand is between 35 to 65%. The active calcium carbonate attains high levels up to 20% in certain conditions.

Nitrogen is found to be considerably low and organic matter content is actually null. The soil reaction is alkaline ($\text{pH} \geq 7.4$). It might have salt accumulation at the surface horizon.

These soils are mostly discontinuous and due to their light characteristics, thus might be subjected to wind erosion. The large spatial distribution of bare rocks in places of the accumulation of this soil determines the desertic features.

Agriculture is quite impossible without irrigation. Places like Hermel, Laboue, Qaa and Ksair could be considered like oasis in the middle of such soils.

Soils on marl and the rendzines

- *White grayish soils (rendzina) (34)*

They are mainly located on white marl (Senonian and Eocene). Clay particles are 20% and contains little Fe_2O_3 (less than 10%) and the ratio of $\text{SiO}_2/\text{Al}_2\text{O}_3$ varies between 2 and 3. In most cases, these soils are poorly developed. They constitute only 5% of the area.

Total calcium carbonate content reaches 60 to 80% with 20 to 40% of active form. Under such characteristics, these soils in steppic climate (north Bekaa) has clear tendency to develop calcic layer or horizon. The pH, always alkaline, reaches 8 in Bekaa. The C/N ratio might range between 12 and 16.

It holds sufficient levels of nitrogen and potassium but has a low level of phosphoric acid. Organic matter content is generally low.

⁵ (40) discontinuous; (41) continuous

The agricultural characteristics of such soils are sometimes contradictory. In some places, these soils are completely bare. In other locations they appear to be very convenient for the cultivation of olives, almonds and vines. This fertility could be explained in arid areas because deep roots find its way to nutrients and water through the cracks of the parent materials.

Mixed soils

- Mixed soils (31, 32 and 33)

Gèze (1956a) adapted this name for soils formed on terrain with its upper part consisting of Lower Cretaceous and sometimes of Upper Jurassic to Middle Cretaceous formations. Therefore, it is a succession and alternation of sandstone, sand, clay, marl, carbonate and ancient basalt. The soils n° 31 are located on marl with bedded limestone. The soils n° 32 are found alternating between marl, limestone and sandstone. The soils n° 33 alternate between marl, limestone, sandstone, and basalt. All three soils are usually in mountainous areas. They make 6% of study area.

The total CaCO_3 content is 30 to 60%, with the active part ranging between 5 to 20%. The pH is always neutral, between 6.9 and 7.

These soils are suitable for all types of cultivation but their spatial distribution being usually in the mountains makes it difficult for intensive agriculture. They could be well adapted for fruit trees of different types. Water could be highly available for fruit trees in such soils with the presence of permeable and impermeable layers across the soil horizons. However, this condition could induce landslides or mass movements, forcing the farmer to consider an efficient drainage system of these soils.

Soils formed on sandstones

- Sandy soils on friable sandstones (17)

The friable sandstones at the base of Cretaceous is largely found in Lebanon. They are formed by particles of quartz linked to limonite. Clay is very low. The pH is acidic of 6.2 to 6.4. Their presence in the area study area is less than 1%.

Soils formed on alluvial, colluvial or fluvial deposits

- Recent fluvial (20)

They are rich in clay (more than 45%), CaCO_3 , and of large particles. They are found next to riverbanks, which are cultivated with field crops and fruit trees in mountain depressions. Their cover in the area of study is less than one percent.

- Landslide or massive landslides (3)

They hold variable content of organic matter (0.5-5%) and (15-30%) CaCO_3 . The pH is alkaline with the average depth of around 1 m and they have high clay content (40-60%). They are rich in large particles (15-40%) and have high infiltration capacity with average water holding capacity. They are covered by deciduous fruit trees and field crops. They are also particularly urbanized. They could be found in the study area at 3.5% coverage.

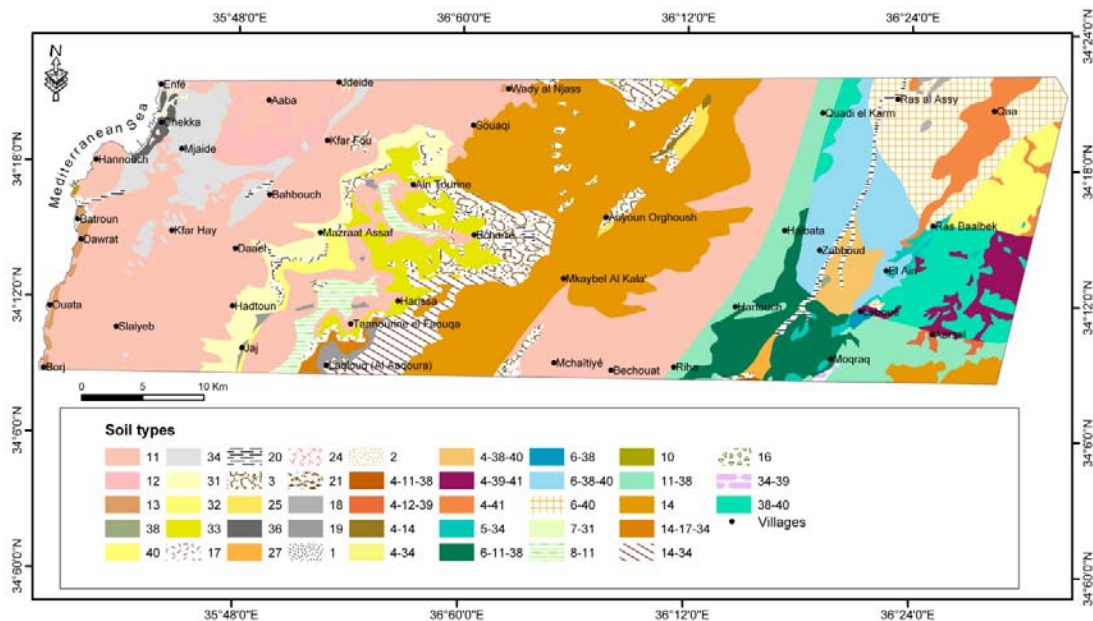


Figure a2. Soils at the study area.

- Alluvium associated with yellowish mountain soils (25)

They are located along the depressions of Mount Lebanon with large particles and with low content of CaCO_3 (around 2%). The cover is oaks, deciduous fruit trees and sometimes field crops.

- Black or greyey soils (36)

They are found next to Chekka in the study area with less than 0.5%. The parent material is the white marl and its degradation forms these soils as alluvium or colluvium. The clay content ranges between 30 and 55%. The $\text{SiO}_2/\text{Al}_2\text{O}_3$ is 1.3 to 2 while the Fe_2O_3 of clay particles is 10 to 17%. The total CaCO_3 varies a lot from one place to another (oscillates between 3.5 and 87%). pH is always alkaline (7.2 to 8). The nutrients have little deficiency especially phosphoric acid and potassium. The C/N ratio is 10 to 16. They are well suited for the cultivation of citrus and bananas.

- Alluvium associated with light chestnut soil (27)

They are characterized by high percentage of large particles. The organic matter content varies a lot. It has considerable total CaCO_3 value (10%) and depth (2 m or more). It is covered by field crops. The presence is less than 0.5%.

- Alluvium associated with red soils (n° 24)

They are located in karstic depressions in the mountains. They are deep (more than 2 m) and relatively low in organic matter (1 to 2%) and rich in large particles. They are cultivated with field crops and deciduous fruit trees.

- Torrential fan deposits (21)

They are rich in sand (47%) and are very rich in large particles (60 to 80%) but poor in organic matter. They are covered by fruit trees (with some olives), field crops and a number of urban settlements. Less than 0.5% is their cover.

Soils on basalt

- Greyey soils (18 and 19)

Basalts erupted in Lebanon in two different geological periods. Soils, however, does not differ much between both formations. In the large plains, clay content is medium (22%). The clay content becomes high (40-50%) in depressions or next to drainage streams. Calcium carbonate content is generally low, ranging between 1 and 5% with some exceptions that might reach 10%. The soil reaction pH is around 7. The nutrients are under deficiency; even the organic matter is low with C/N ratio between 10 and 15. It is admissible for the cultivation of wheat and herbaceous crops. Their coverage is less than one in the study area.

Annex 11

Annex (Published Articles)

Article 1.

Lebanese Science Journal, Vol. 8, No. 2, 2007

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CONTRIBUTION TO THE CHARACTERIZATION OF FOREST FRAGMENTATION ON THE EASTERN FLANK OF MOUNT LEBANON OVER 33 YEARS

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ABSTRACT

Fragmentation has become central issue in ecological studies as it is detrimental for biodiversity across the landscapes. It threatens forest resources throughout the world. This study investigates the changes and fragmentations of the forests spatial configuration over 33 years (1965 forest map at 1/50,000 and 1998 landcover map at 1/20,000) at the Eastern slope of Mount Lebanon. Legends on both maps were first harmonized and entered into atypical forest fragmentation analysis. Spatial scale was then resampled for straight forward analysis. A set of landscape indices were applied to quantify changes. Junipers and oaks are the main forest types at the study area. The landscape over the study area showed to be highly fragmented and subjected to severe degradations. In particular, total forest area decreased by 47% (from 33,369 to 17,668 ha) during the investigated period. Patch number increased by 5 times, mean patch size decreased by 17 times and total edge has doubled. Inside-outside patch forest fragmentation analysis was used to detect the most degraded area and determine the forest regeneration dynamics. This paper provides significant contribution to the analysis of forest fragmentation in the Mediterranean environments using older forest spatial data toward the investigation of forest ecological conditions. Forest fragmentation analysis, however, requires lower level biodiversity investigations such as species level.

Keywords: fragmentation, forests, oaks, junipers, Lebanon, landscape indices, monitoring, landcover

INTRODUCTION

Although it is prominent that conservation of biodiversity is one of the pressing issues of this time, fragmentation of the forest ecosystems remains one of the serious causes of biodiversity depletion. Forest fragmentations are what happen when large contiguous forest patch splits into several smaller ones (Forman & Godron, 1986). Fragmentation is considered as an indicator of biodiversity loss (Wilcox & Murphy, 1985; Lauga & Joachim, 1992) through reduction of habitat area and breaking it into isolated pieces (Opdam *et al.*, 1993; di Castri & Younés, 1995; Hunter, 1996). In fragmented patches there maybe enough place for

one or few individuals but not for a population (Burel & Baudry, 2003). Smaller forest patches get more susceptible to external disturbances than larger ones (Diamond, 1975; Nilsson and Grelsson, 1995).

Biodiversity loss and fragmentation are mainly due to physical environmental changes as a result of human activities such as logging, conversion of landscapes to agricultural land, overgrazing, mining, urban development, roads, water harvesting reservoirs, water diversion, etc (Hunter, 1996; Noss and Cooperrider, 1994; Reed *et al.*, 1996). Forest fire might also contribute in fragmenting and degrading landscapes (Mladenoff *et al.*, 1993). Important number of landscape metrics has been developed in literatures to quantify and monitor fragmentation of a landscape (McGarigal & Marks, 1994). Fragmentation analysis through landscape indices adds comprehensive concepts in the advancement of the forest patches (Franklin, 1994; Boentje & Blinnikov, 2007).

Lebanese government has acknowledged the importance of saving the biotic richness through signing the Convention on Biological Diversity (CBD) in 1992 and ratifying it in 1994. Abi Saleh *et al.* (1996) estimated that only 8% of the Lebanese territory is forests; the National Forest Assessment speaks about 13.3% of a total forest area (NFA, 2005). Although a country total forest coverage rate is a crucial index in monitoring forest resources, other indices are more informative (O'Neill *et al.*, 1988). In Lebanon, forests have been cleared through ages mainly because of human pressure in various forms (MoA/UNEP, 1996). Scientists nowadays are concerned to conserve what remained out of the older forests (MoE/UNEP, 1998). Since Landscape pattern analysis is not applied in Lebanon, it is important to analyze the history of forest stands and changes through time in order to better orient conservation measures. Forest fragmentations were not investigated in previous studies in Lebanon.

Existing landcover and forest maps of different years are valuable data sources that could be used to analyze forest dynamics and especially fragmentation. However, these maps usually hold different legends and spatial scales that should be harmonized before any computations. Landscape analysis is highly sensitive to changing map scale (Ferraz *et al.*, 2006). Inaccurate use of different spatial scale maps will definitely terminate into misleading results and consequently misinterpretation; this is especially the case when comparing landscape indices (Gustafson, 1998). Coarse spatial scale landscape representation usually indicates a landscape with lower fragmentation status (Saura, 2004) than if the landscape where studied on finer spatial scales.

Changing spatial scale on a map is not a straight forward procedure, and is mainly performed on urban blocks and roads (Zhilin & Choi, 2002) and to a lesser extent on forest spatial data. A standard generalization methodology or changing map spatial scale does not exist.

This paper provides considerable contribution to the analysis of forest fragmentation in Mediterranean environments, using available forest spatial data. Such forest spatial change analysis helps in future ecological management plans. Overall forest coverage is one important index that could be extracted out of spatial data sources such as existing thematic maps. Even if those maps were created by different authors of various backgrounds, for various purposes, and with various perspectives, they can be compared and used for ecological assessments if special treatments are undertaken.

MATERIALS AND METHODS

Study area

Situated on the Eastern shore of the Mediterranean Sea, Lebanon is part of the region which occupies the junction between Europe, Asia and Africa, with a surface area of 10,452 Km². The study area expands over 897 Km² of lands along the Eastern slope of Mount Lebanon with 81 Km north-south and 8-16 Km East-West (Figure 1). It had undergone important forest changes and landscape degradation (Masri *et al.*, 2002; Jomaa & Bou Kheir, 2003) and has been classified as subjected to high and very high desertification risk in Lebanon (CoDeL, 2001). Therefore, existing forests are fragile and had undergone irreversible degradation processes.

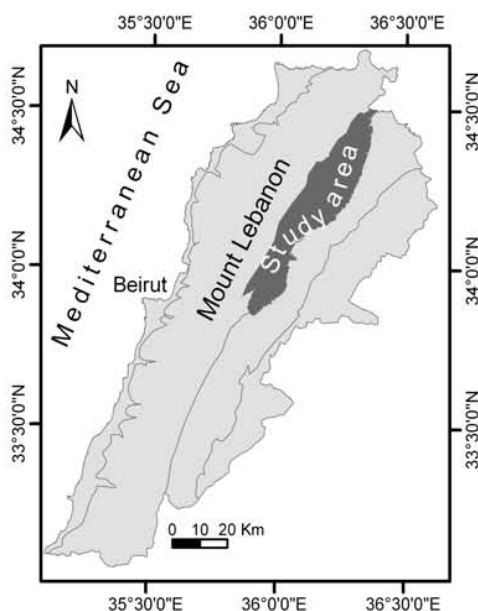


Figure 1. Location of the study area along the Eastern side of Mount Lebanon.

The study area is characterized by Mediterranean type of climate with vegetations of mostly presteppic formation. Forests are mainly oaks (*Quercus calliprinos* and *Q. infectoria*) and junipers (*Juniperus excelsa*) (Abi Saleh *et al.*, 1996). Soils consist of 52% red-soils and 34% of yellowish-mountainous-soils (Gèze, 1956). Rocks are mainly formed of dolomitic limestones that cover 92% of the study area (Dubertret, 1953). At the study area, annual precipitation is proportional to elevation and ranges between 300 and 1400 mm (Plassard, 1971). Elevation starts from 1100 m to the East and reaches 3050 m to the west. This large elevation gradient area fits within a distance of 16 Km, which have contributed in magnifying the irreversible losses on the vegetation cover.

Data used

The used spatial data consists of two thematic maps: the 1965 forest map (1/50,000 spatial scale) and the 1998 landcover map (1/20,000 spatial scale).

(1) 1965 forest map

Forest mapping in Lebanon started with the aerial mission of 1962, which resulted in the production of the 1965 forest map at a 1/50,000 spatial scale (El Husseini & Baltaxe, 1965). Since then, and for the past 38 years, it has never been updated. The study area is included within six sheets that were merged and digitized using a geographic information system (facilities included in ArcGIS 9.2 software pack). Four different forest types were recorded at the study area: (1) oaks (coppice and stands), (2) pines, (3) cedars, and (4) junipers (Table 1).

TABLE 1
Forest Types at the Study Area in 1965

| # | Forest type | Crown closure (%) | Species |
|---|---------------------|-------------------|---|
| 1 | Oak coppice | >30 | <i>Quercus calliprinos</i> , <i>Q. infectoria</i> , with or without some <i>Pinus brutia</i> , <i>Juniperus</i> and <i>maquis spp</i> in varying portions |
| | | 10-30 | |
| | Oak standards | >30 | <i>Quercus calliprinos</i> , <i>Q. infectoria</i> , <i>Q. brantii</i> , <i>Q. cerris</i> |
| | | 10-30 | |
| 2 | <i>Pinus brutia</i> | >40 | |
| | | 10-40 | Rarely <i>Pinus halepensis</i> |
| | <i>Pinus pinea</i> | >40 | |
| | | 10-40 | - |
| 3 | Cedar | >40 | <i>Cedrus libani</i> with or without <i>Q. spp</i> , <i>Juniperus spp.</i> , and <i>Abies silica</i> , in varying portions |
| | | 10-40 | |
| 4 | Juniper | >30 | <i>Juniperus excelsa</i> , <i>J. foetidissima</i> , with or without <i>Quercus calliprinos</i> and <i>Q. infectoria</i> in varying proportions |
| | | 10-30 | |

(2) 1998 landcover map

The existing landcover map of 1998 was derived from satellite images of IRS-1D (panchromatic 5 m spatial resolution) and Landsat TM 5 (30 m spatial resolution) (MoA, 2002). The IRS-1D image was merged to bands number 2, 4 and 7 of the Landsat TM 5, using the Principle Component Merging method. This process produced a False Color Composite (FCC) image (Refer to the map technical report for more details).

Legends concerning forests on the 1998 landcover map are generally separated between coniferous, broadleaved and open mixed woodlands with their coverage-density (Table 2).

TABLE 2

Summary of the Forest Types at the Study Area in 1998

| General forest type | coverage | Forest types |
|----------------------|----------|--|
| Coniferous Woodland | Dense | <i>Pinus pinea</i> , <i>Pinus Brutia</i> , <i>Cedrus libani</i> , <i>Cupressus sempervirens</i> , <i>Abies cilicica</i> |
| | Clear | <i>Pinus</i> spp., <i>Cedrus</i> spp., <i>Juniperus</i> spp., <i>Abies</i> spp., <i>Cupressus</i> spp. |
| Broadleaved Woodland | Dense | Mixed woodland |
| | Clear | <i>Quercus</i> spp., Other type of broad leaves |
| Open mixed wood land | Clear | Mixed wood land |

Semantic analysis of the legends

Legend comparison is a first phase when comparing different thematic maps. Semantic analysis of the legends of both maps is necessary to harmonize forest types to facilitate comparison. In particular, objects of same forest types but of different cover density were joined together in a GIS environment (Table 3).

TABLE 3

Harmonizing the Legends of the Used Maps

| Forest legend (1965) | Legend harmonizing | Forest legend (1998)* |
|---|--------------------|--------------------------------------|
| Oak coppice or standard 10-30%** | Oaks | Forest of <i>Quercus</i> spp, dense |
| Oak coppice or standard >30% | | Forest of <i>Quercus</i> spp, sparse |
| <i>Pinus brutia</i> and <i>Pinus pinea</i> 10-40% | Pines | Pines dense |
| <i>Pinus brutia</i> and <i>Pinus pinea</i> >40% | | Pines clear |
| Cedar 10-40% | Cedars | Cedars dense |
| Cedar >40% | | Cedars clear |
| Junipers 10-30% | Junipers | Forest of <i>Juniperus</i> spp, |
| Junipers >30% | | sparse |

*Forest found at the study area.

**Percentage of cover density (see Tables 1 and 2).

Since, cover density on both maps can not be matched because a >30% forest cover in the 1965 forest map will not coincide with dense forest of the 1998 landcover map, legend harmonizing targeted only forest types.

Forest change analysis

An original assessment of the forest change was developed that opens the road toward using different spatial scale thematic maps for comparison purposes. The analysis was

divided to what was defined as (1) inside-outside patch analysis and (2) forest fragmentation analysis.

(1) Inside- outside patch analysis

- In this paper, an inside patch analysis is defined as the investigation of forest changes within each older forest patch. Limits (edge) of each forest patch existing on the 1965 forest map were extracted and overlaid on the forest layer obtained from the 1998 landcover map. This step allowed us to search inside each forest patch of 1965 (old forest patches) what still exists in 1998. Although both maps (1965 forest map and 1998 landcover) have different spatial scale, their comparison became possible, using this inside outside analysis technique. Resampling of one map (raster format) to reach other map spatial scale using GIS conveniences could be a solution. However, this process accumulates errors and alters the map spatial data logarithmically which might not approach the real situations. Since any artificial modification in a map scale leads to errors, a comparison method is developed between maps that does not necessitate spatial scale changes. The important point is that the edge (border or limit) of a forest patch will have minor changes between maps of 1/20,000 and others of 1/50,000 spatial scale. These minor changes are, actually, simplification of edge complexity (Echeverria *et al.*, 2006) and not elimination of spatial information. Consequently, edges of 1965 forest areas were investigated from the inside using data of 1998 landcover map. Only limits of forests in 1965 were used and searched for changes in landcover.

- The inside forest patch comparison also provided landcover change matrix (transition matrix) and fragmentation analysis. Since only forest data of 1965 are available, the inside forest change matrix performed through direct comparison with 1998 landcover data. Changes of landcover on the inside of each patch were investigated in a table matrix.

- Fragmentation of each forest patch was inspected in particular approach. Landscape indices were calculated inside the 1965 forest limits using forest data of 1998. Number of the 1998 forest patches (Patch Number) inside the limits of the 1965 forest patch was the first indicator. Total forest coverage in 1998 remained inside each of the 1965 forest patches is also an important change examination for fragmentation analysis (Figure 2). Each forest coverage percentage in 1998 found on the inside of the 1965 forest patch is followed by Mean Nearest Neighbor (MNN) and mean patch size (MPS) calculations. MNN indicates the distance between patches, which when computed together with forest coverage for (inside) each patch will result to a further fragmentation analysis. Forest residues are named on the 1998 forest patches that were remained inside the 1965 forest ones. The forest residues MPS was compared to the original patch size (1965 patch size) and plotted of the residues patch number. This analysis separated the 1965 forest patches between different fragmentation degrees.

- Outside patch analysis was also conducted in order to know regeneration dynamics of the forests. The percent coverage of the forests in 1998 was calculated to the outside of the 1965 forest patches within the study area. New forests to the outside might be the result of regeneration or rehabilitation for the forest resources within the study area.

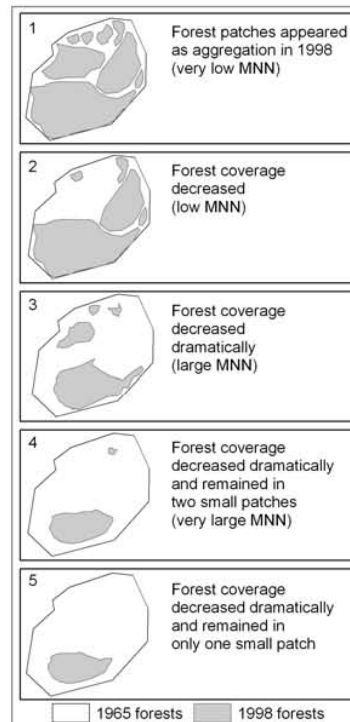


Figure 2. Comparison overlay between 1965 and 1998 forest patches.

(2) Forest fragmentation analysis

A general overview was required for the overall situation of fragmentation within the study area after considering each (inside) forest patch analysis. First, both maps were converted into raster format using GIS. Then resampling was performed to obtain two raster maps with 50 m pixel size each. This step degraded the spatial information of the 1998 landcover map to approach the 1965 forest map spatial scale.

This fragmentation analysis summarized the status overall the landscape. Quantification and fragmentation analysis of the spatial forest data were calculated based on a set of landscape metrics: patch number (PN), mean patch size (MPS), largest patch index (LPI), area weighted mean patch fractal dimension (AWMPFD), mean nearest neighbor distance (MNN) and total edge (TE). These selected metrics characterize the spatial fragmentation for the landscape. Patch number (PN) and mean patch size (MPS) should be used complementarily since high PN and low MPS values characterize fragmented landscapes (Leitao & Ahern, 2002). The LPI produces useful information of overall patch degree of change.

RESULTS

Changes in forest cover

Landcover change over the 33 year period was inserted into a transition matrix (Table 4). Over the entire period, agriculture replaced about 2% of the forests while only about 0.2% of urban occupied these forest areas. Grasslands have abolished the largest forest area that is about 20% followed by rock outcropping for about 5.6%. About 77% of oaks and only 25% of junipers persisted over the investigated period. Cedar forests shown on the 1965 forest map were not found on the landcover map of 1998. These forests were mainly replaced by junipers. Pine forests increased between 1965 and 1998 by about 62 times but they were not reported in the same geographic location. Pine forests located in the 1998 map have replaced some of the oaks and junipers ones.

TABLE 4

The Transition Matrix of the Forest Patches between 1965 and 1998 (ha)

| 1965 | 1998 | | | | | | | Total |
|----------|----------|----------|--------|------------|---------|-------------|-------|----------|
| | Oak | Junipers | Pines | Grasslands | Rocks | Agriculture | Urban | |
| Oak | 11105.68 | 202.51 | 119.05 | 2018.92 | 452.11 | 301.85 | 62.35 | 14262.48 |
| Junipers | 697.62 | 5277.88 | 130.57 | 9456.60 | 4345.60 | 453.25 | 20.30 | 20382.27 |
| Cedars | 239.00 | 37.74 | 0.00 | 30.33 | 2.59 | 0.19 | 0.00 | 309.86 |
| Pines | 2.85 | 0.72 | 0.00 | 0.44 | 0.00 | 0.00 | 0.00 | 4.01 |
| Total | 12045.16 | 5518.85 | 249.63 | 11506.29 | 4800.30 | 755.74 | 82.65 | 34958.61 |

Forests in 1998 covered 17,668 ha, accounting for 18.7% of the studied area. However, forests in 1965 were in 33,369 ha or 35.3% of the total area (Figure 3). The studied landscape showed a decrease of the forest area by 50% within the investigated period (1965-1998). Patch number (PN) increased by about 5 times. Juniper forests were the dominant forest type in 1965 (Figure 4). Oaks showed important coverage, whereas pines and cedars represented less than 1% of the studied area.

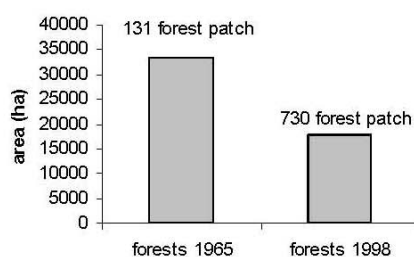


Figure 3. The total forest area in both years.

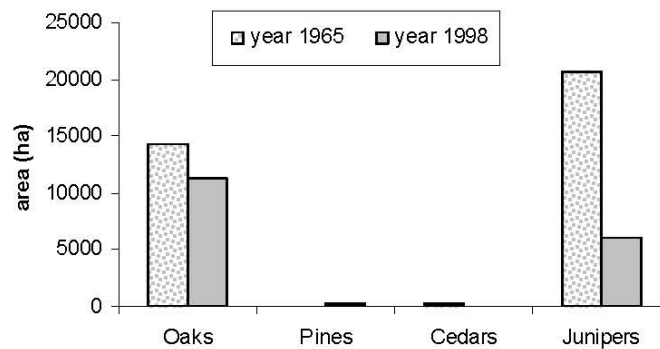


Figure 4. Changes of forest coverage between 1965 and 1998 by forest type.

Inside-outside patch analysis

About 55% of the 1965 forest patches have lost more than 50% of their original area by the year 1998 (Table 5). Out of the 131 forest patches identified in 1965, 15 have totally disappeared in 1998. Moreover, 23% of the patches lost more than 80% of their forest area reported in 1965. Only 9/131 patches kept their original forest coverage, *i.e.*, no sign of fragmentation was detected.

The MNN ranged from 0 to 2 km between 1998 forest patches that are located inside the 1965 forests patches. Only 12 forest patches appeared to have very low MNN accompanied with large forest coverage. These 12 patches could be considered as somehow preserved or having witnessed minor changes.

TABLE 5

Forests of 1998 to the Inside of the 1965 Forest Patch Limits

| | Forest cover in 1998 (%) | | | | | |
|------------------------|--------------------------|--------|-------|-------|-------|--------|
| | 0 | 0-20** | 20-50 | 50-70 | 70-90 | 90-100 |
| Number of patches (%)* | 11.5 | 23 | 20.6 | 19 | 19 | 6.9 |

* From the 1965 forest patches

** Excluding 0% forest cover.

Large number of 1965 forest patches had undergone important loss of size and significant segmentations into small patch residues in 1998 (Figure 5). The MPS of the residue forests formed mainly less than 50% of the original patch size of 1965. Very small MPS percentages are followed with high patch numbers which indicate complete loss of the forests.

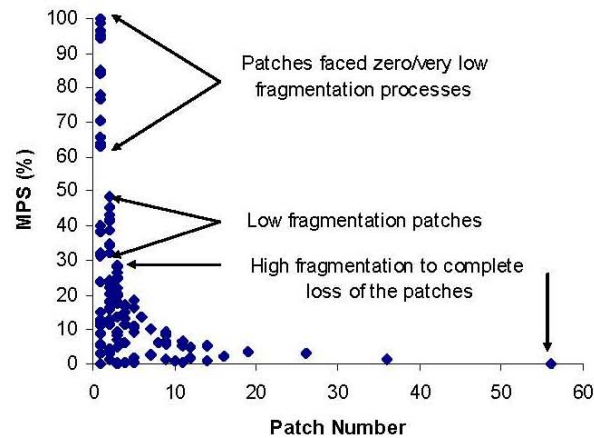


Figure 5. MPS percentage of forest residues from original 1965 forests plotted on their patch number.

Despite an overall dramatic decrease of total forest coverage over the study area, forest regeneration calculated as the increase of forested areas outside the 1965 forest patches, reached 4714 ha.

Landscape spatial analysis

The increase in number of the forest patches (from 131 to 730 patches) was followed by decrease of the patch size as the mean patch size index (MPS) determined (Table 6). The number of patches increased differently for each forest type. The patch number for junipers had increased by 10 times, while for oak it had augmented by 7 times. The largest patch occupied 45% of the total landscape (studied area) in 1965 while it decreased to 18% in 1998. These indices indicate that forest patches undergone important decrease in their size during the studied period. The AWMPFD demonstrates similar degree of shape complexity between the investigated years. The MNN decreased which could indicate better patch proximity or connectivity in 1998. In reality, this decrease in MNN is the result of large increase in the number of the small forest patches next to each other. The total edge increased dramatically with the increase in forest patch number.

TABLE 6

Landscape Spatial Indices for 1965 and 1998

| Year | PN | MPS (ha) | LPI (%) | AWMPFD | MNN (m) | TE (km) |
|------|-----|----------|---------|--------|---------|---------|
| 1965 | 131 | 861.4 | 45 | 1.21 | 157 | 955.4 |
| 1998 | 730 | 50.8 | 18 | 1.25 | 116 | 2120.6 |

Areas of severe forest changes were located to the north of the studied area (Figure 6). Junipers were largely affected in this part of the landscape.

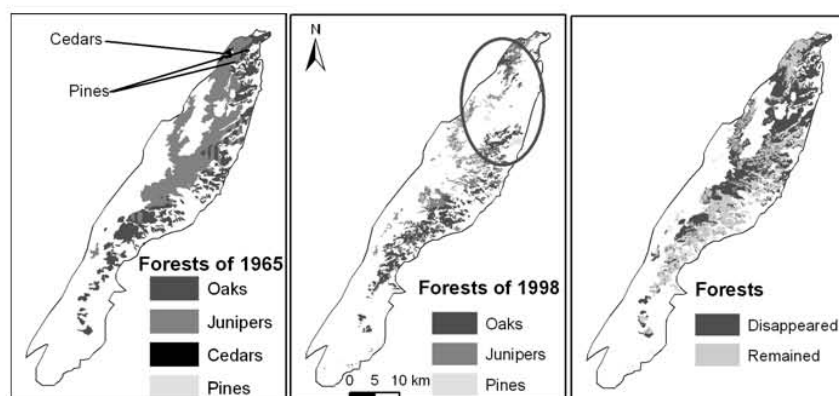


Figure 6. Spatial forest changes during the studied period.

DISCUSSION AND CONCLUSION

Forests at the study area have undergone severe loss as they were mainly changed to grasslands (Table 4), bearing the prints of overgrazing activities and continuous human interventions by logging (Baalbaki, 2000). Rock outcrops have appeared within patches that were previously covered by forests which highlight the vulnerability of the top soil to erosion once forest cover is lost. These findings corroborate those of the desertification map of Lebanon scale 1/200 000 (CoDel, 2001) as the study area have been classified as highly vulnerable to land degradation and desertification.

Nor agriculture, nor constructions were significant as land use changes over the study area (Table 4). This is mainly due because the study area did not represent over the past year an attractive spot for farmers that preferred to cultivate the valleys and avoiding the harsh physical efforts related to terracing mountain slopes.

Oak species have the ability to grow new sprouts when subjected to grazing and/or cutting (Salleo *et al.*, 2002). This can explain why, despite intensive degradation, nearly 77 % of patches previously identified as oak stands in 1965, were still colonized by oaks in 1998 (Table 4).

Even though Juniper forests have often been reported in fragmented populations (Talhouk *et al.*, 2001), these results revealed a drastic decrease in their distribution as, over the studied period (1965- 1998), as much as three times their area have been lost. Informal discussion with local herders and mountain residents confirmed that juniper wood was largely used for home constructions in the late sixties.

Pine forests patches in the 1965 map were not shown in the 1998 map, whereas, pine patches located in different geographical spots over the study area were reported. It is highly probable that the patches identified as pine stands in the 1998 land cover map, resulted from plantation of pine trees.

Cedar forests within the study area disappeared during the investigated period. However, this result might be related to the fact that cedars were limited in 1965. These cedar forests are also surrounded by junipers which might have complicated the differentiations between both coniferous forests in a satellite image. However, such remote sensing and landscape analysis is always in need of field surveys in order to outcome conclusive findings.

The Eastern flank of Mount Lebanon had low forest coverage in 1965 and showed important forest degradation during the entire studied period. Over the study area, almost 50 % of the total forest cover has been lost in 33 years, mainly affecting juniper stands. Previous works, on the same area and time period, reported forest area decrease by 58% (Masri *et al.*, 2002) on use of 1/200 000 agriculture map (Boulos, 1963) and landcover map 1987 1/50 000 (FAO, 1990) and classification of Landsat TM and SPOT XS of 1998. No scale harmonization was performed for those results. Harmonizing maps especially what concerns spatial scale is compulsory for landscape spatial scale analysis.

Total forest cover describes only one dimension of ecological problems encountered at the study area. Landscape indices computations and the inside-outside patch analysis determined the entire view of forest loss and fragmentation. The exact location of major changes and the degree of severity has been investigated. These are important steps toward better management plans.

Fragmentation of forest patches was studied on patch by patch analysis and then over the landscape. These results suggest that the forests over the study area of Mount-Lebanon have reached the residual type of forests (Figure 6), identified in more than 100 locations that faced important degradations (Table 5).

Inside-outside forest patch analysis determined the patches that have faced severe fragmentations. Landscape indices calculated to the inside of the older forest patches expressed the level of degradations for each patch. Landcover transition matrix based on the limits (edge) of the 1965 forest patches was also an important output of the inside-outside patch analysis. These results together with forest regeneration investigations add to the importance of applied technique.

The exact ecological effect of such severe fragmentation remains unknown until monitoring changes on species level is performed. However, it is clear that the large fragmentation and forest loss in the area will be accompanied by enormous change on lower levels of biodiversity such as species richness and evenness. Species monitoring studies suggested that even small scale fragmentations of the forests can have adverse effect on species viability (Stevens & Husband, 1998).

Previous studies have used various sources of spatial data for landscape analysis. However, they directly resampled resolution (grain) of the maps to reach homogenous spatial scale (Boentje & Blinnikov, 2007). This algorithmic alteration of spatial data might completely deviate from reality or ground truth. The error of the results might increase dramatically. This suggested methodological analysis (inside-outside) kept the used maps in their original scale (product original spatial scale). The used landscape indices and techniques were able to define areas of major forest loss and fragmentations. Although overlaying coarse scale map on a detailed one also holds errors, it enables detailed understanding on precise

forest patch location. However, it is important to use in similar studies maps that do not have very large difference in spatial scales (Echeverria *et al.*, 2006).

Forest dynamics could be investigated using thematic maps; however, carefulness must be taken concerning spatial scale and legend differences. Comparable legends of different maps acquired at various dates and for diverse purposes can be attained through semantic analysis.

Perceptions of the map authors have to be considered in details when defining new legends. Comparable spatial scale could be managed through generalization of the highest spatial resolution map to reach the coarser scale. Generalization of a map scale could be applied for definite and particular objectives, *e.g.*, ecological analysis (Hessburg *et al.*, 1999). Landcover maps comparison does not only need an algorithmic experience; it is a research process that requires field knowledge and thematic expert decision. More studies on map harmonization are needed as it is certain that most countries around the world have maps of different spatial scales and legends.

Landscape indices demonstrated to be useful tools in exploring variability of a landscape through time. They also provide valuable ecological information for the investigated site, *e.g.*, description of the forest conditions for management purpose (Cumming & Vernier, 2002).

Monitoring through remote sensing and field surveys can effectively support the analysis of fragmentation processes. However, variations in satellite image resolutions highly influence landscape pattern analysis. Data on edaphic factors and human interventions also help in forest fragmentation analysis (Krummel *et al.*, 1987; De Cola, 1989; Turner, 1989). Comprehensive analysis of landscape fragmentation is possible through overlaying additional thematic layers like urban areas, roads, mines and socio-economics, especially that climate changes can significantly amplify the fragmentation process initiated by anthropogenic activities.

This type of integrated analysis are highly required in Lebanon as restoration and conservation practices could not be engaged on a sustainable manner without better understanding of the forest fragmentation processes over the last three decades.

This paper has contributed to an ecological characterization of changes in forest resources, using different spatial data sources, and has provided important spatial information on the Mediterranean forests dynamics that are essential in future management plans.

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REFERENCES

- Abi Saleh, B., Nasser, N., Hanna, R., Safi, N., Safi, S. Tohmé, H. 1996. *Etude de la diversité biologique du Liban*. Ministère de l'Agriculture, Liban, PNUE, projet GF/6105-92-72, publication no. 3., pp. 146.
- Baalbaki, A. 2000. *Local and sectoral development, debate on Lebanese concept and experiences*. (Arabic), Faculty of Social Science, Lebanese University, pp. 197.
- Boentje, J.P., Blinnikov, M.S. 2007. Post-Soviet forest fragmentation and loss in the Green Belt around Moscow, Russia (1991–2001): a remote sensing perspective. *Landscape and Urban Planning*, in press.
- Boulos, F.B. 1963. Carte agricole du Liban avec divers aspects météorologique, touristique, administratif et social. Conseil National de la Recherche Scientifique, Liban, 3ème édition, 1980.
- Burel, F., Baudry, J. 2003. *Landscape ecology: concepts, methods and applications*. Technique et Documentation, Paris, Science Publishers, Inc., pp. 362.
- CoDeL. 2001. *Combating desertification in Lebanon*. A joint project of GTZ (Germany) and Ministry of Agriculture (Lebanon).
- Cumming, S., Vernier, P. 2002 Statistical models of landscape pattern metrics, with applications to regional scale dynamic forest simulations. *Landscape Ecology*, 17: 433-444.
- De Cola, L. 1989. Fractal analysis of a classified Landsat scene. *Photogrammetric Engineering and Remote Sensing*, 55: 601–610.
- Diamond, J.M. 1975. The island dilemma: lessons of modern biogeographic studies for the design of natural reserves. *Biological conservation* 7: 129-146.
- di Castri, F., Younès, T. 1995. Introduction: Biodiversity, the emergence of a new scientific field-its perspectives and constraints. In: di Castri, F., Younès, T. (eds). Biodiversity, science and development: towards a new partnership. Wallingford, CAB International, pp. 1-11.
- Dubertret, L. 1953. Carte géologique de la Syrie et du Liban au 1/50,000^e. 21 feuilles avec notices explicatives, République Libanaise, Ministère des Travaux Publics, Imprimerie Catholique, Beyrouth, 66 p.
- Echeverria, C., Coomes, D., Salas, J., Rey-Benayas, J.M., Lara, A., Newton, A. 2006. Rapid deforestation and fragmentation of Chilean temperate forests. *Biological conservation*, 130: 481- 494.
- El Hussein, K., Baltaxe, R. 1965. Forest type map at 1/50,000 scale. Forestry Education, Training and Research Project, Green plan, Lebanon, United Nations Special Fund/FAO.
- FAO 1990. Lebanon landcover map of 1987 at scale 1/50 000. (twelve sheet).
- Ferraz, S.F.B., Capão, L.M.S.A.C., Vettorazzi, C.A. 2006. Temporal scale and spatial resolution effects on Amazon forest fragmentation assessment in Rondônia. *International Journal of Remote Sensing*, 27(3): 459-472.
- Forman, R.T.T., Godron, M. 1986. *Landscape Ecology*, John Wiley & Sons, New York.
- Franklin, J.F. 1994. Developing information essential to policy, planning and management decision-making: The promise of GIS. In: V. Alaric Sample (Editor), Remote Sensing and GIS in Ecosystem Management, Island Press, Washington DC, pp. 18-24.
- Gèze, B. 1956. Carte de reconnaissance des sols du Liban au 1/200,000^e. République Libanaise, Ministère de l'Agriculture, Direction de l'Enseignement et la Vulgarisation, Station Agronomique Libano-Française, notice explicative, 52 p.

- Gustafson, E.J. 1998. Quantifying landscape spatial pattern: what is the state of art? *Ecosystems*, 1: 143-156.
- Hessburg, P.F., Smith, G.B., Salter, R.B. 1999. Detecting change in forest spatial patterns from reference conditions. *Ecological Applications*, 9: 1232-1252.
- Hunter, Jr. M.L. 1996. Benchmarks for managing ecosystems: are human activities natural? *Conserv. Biol.*, 10: 695-697.
- Jomaa, I., Bou Kheir, R. 2003. Multitemporal unsupervised classification and NDVI to monitor land cover change in Lebanon. *Options Méditerranéennes*, Série B, (46): 43-49.
- Krummel, J.R., Gardner, R.H., Sugihara, G., O'Neill, R.V., Coleman, P.R. 1987. Landscape patterns in a disturbed environment. *Oikos*, 48: 321-324.
- Lauga, J., Joachim, J. 1992. Modeling the effects of forest fragmentation on certain species of forest-breeding birds. *Landscape Ecology*, 6(3): 183-193.
- Leitao, A.B., Ahern, J. 2002. Applying landscape ecological concepts and metrics in sustainable landscape planning. *Landscape and Urban Planning*, 59: 65-93.
- Mandlebrot, B. 1967. How long is the coast of Britain? Statistical self-similarity and fractional dimension. *Science*, 156: 636-638.
- Masri, T., Khawlie, M., Faour, G. 2002. Landcover change over the last 40 years in Lebanon. *Lebanese Science Journal*, 3(2): 17-28.
- McGarigal, K., Marks, B.J. 1994. *FRAGSTATS: spatial pattern analysis program for quantifying landscape structure*. Reference manual, Forest Science Department, Oregon State University, Corvallis Oregon, 62 p.+ Append.
- Mladenoff, D.J., White, M.A., Pastor, J., Crow, T.R. 1993. Comparing spatial pattern in unaltered old-growth and disturbed forest landscapes. *Ecological Applications*, 3: 294-306.
- MoA 2002. Landcover map of Lebanon-obtained from satellite images of the year 1998 (Landsat TM 5 merged to IRS panchromatic). Prepared by the Lebanese National Council for Scientific Research (CNRS), Remote Sensing Center, with the collaboration of IAURIF (Institut d'Aménagement et d'Urbanisme de la Région d'Ile de France), LEDO program, UNDP, Ministry of Agriculture and Ministry of Environment (Lebanon).
- MoA/UNEP 1996. *Etude de la biodiversité du Liban*. Ministry of Agriculture, Lebanon/UNEP, project GF/6105-92-72, report, publication no. 9.
- MoE/UNEP 1998. *National biodiversity study and action plan*. Ministry of Environment. Lebanon/UNFP, biodiversity, GEF.
- NFA 2005. *National forest and tree assessment and inventory*. Technical Corporation Program, Lebanon (TCP/LEB/2903) between 2003 and 2005, Ministry of Agriculture.
- Nilsson, C., Grelsson, G. 1995. The fragility of ecosystems: a review. *Journal of Applied Ecology*, 32: 677-692.
- Noss, R. F., Cooperrider, A.Y. 1994. *Saving nature's legacy*. Island Press, Wash. D.C., 416 pp.
- O'Neill, R.V., Krummel, J.R., Gardner, R.H., Sugihara, G., DeAngelis, D.L., Milne, B.T., Turner, M.G., Zygmunt, B., Christensen, S.W., Dale, V.H., Graham, R.L. 1988. Indices of landscape pattern. *Landscape Ecology*, 1: 153-162.
- Opdam, P., Van Apeldoorn, R., Schotman, A., Kalkhouson, J. 1993. Population responses to landscape fragmentations. In: C.C. Vos and P. Opdam, *Landscape ecology of a stressed environment*, Chapman Hall, Cambridge, pp. 145-171.
- Plassard, J. 1971. Carte pluviométrique du Liban à l'échelle de 1/2^{00.000}e. République Libanaise, Ministère des travaux publics, Direction Générale de l'Aviation Civile.

- Reed, R.A., Johnson-Barnard, J., Baker, W.L. 1996. The contribution of roads to forest fragmentation in the Rocky Mountains. *Conservation Biology*, 10: 1098–1106.
- Salleo, S., Hamze, M., Jomaa, I., Pitt, F., Nardini, S. 2002. Differential drought resistance of two Mediterranean oaks growing in the Bekaa valley (Lebanon). *Plant Bioscience*, 136(1): 91-100.
- Saura, S. 2004. Effects of remote sensor spatial resolution and data aggregation on selected fragmentation indices. *Landscape Ecology*, 19: 197-209.
- Stevens, S.M., Husband, T.P. 1998. The influence of edge on small mammals: evidence from the Brazilian Atlantic forest fragments. *Biological Conservation*, 85: 1-8.
- Talhok, S.N., Zurayek, R., Khury, S. 2001. Conservation of coniferous forests of Lebanon: past, present and future prospects. *Oryx*, 35(3): 206-215.
- Turner, M.G. 1989. Landscape ecology: the effect of patterns on process. *Annu. Rev. Ecol. Syst.*, 20: 171-191.
- Wilcox, B.A., Murphy, D.D. 1985. Conservation strategy: the effects of fragmentation on extinction. *American Naturalist*, 125: 879-887.
- Zhilin, L., Choi, Y.H. 2002. Topographic map generalization: association of road elimination with thematic attributes. *Cartographic Journal*, 39(2): 153-166.

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Landscape spatial dynamics over 38 years under natural and anthropogenic pressures in Mount Lebanon

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ABSTRACT

This research investigates spatial configuration changes of five forest types and introduces uncommon exploration of urban changes in Mount Lebanon. A forest map of 1965 and satellite images of Landsat TM (1987) and Spot 5 (2003) were used. Forest area has reduced by 7%, having low annual deforestation rate (<1%). Oak, cedar and cypress forests increased from 13% to 15%, 0.8% to 1% and 0% to 0.1% respectively; while pine and juniper forests decreased from 1% to 0.8% and 12% to 3% respectively. Grassland covered 20% of the original forest area followed by agriculture and urban. Forest patches were investigated in each 100 m distance from the edge of the old forests. Regenerated oaks were found within the first 100 m. Pine and cedar forests appeared at the 400 m distance. Urban settlements showed 4 m yr⁻¹ moving progress toward forest patches. Landscape indices demonstrated increase in the number of forest patches (from 169 to 432) and in the mean proximity index (from 78.29 to 225.15) and decrease in mean patch area (from 219 to 70 ha) and largest patch index (from 15.45 to 10.32). The observed trends revealed major deforestation and fragmentation in 1965–1987, followed by a lesser deforestation tendency in 1987–2003. Each forest type behaves differently to deforestation and therefore requires special management practices.

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1. Introduction

Although forest ecosystems are among the vital environmental resources on earth, they are facing severe loss and fragmentation. These are major problems in developing countries and important environmental issues worldwide (Laurance, 1999; Telleria et al., 2003; Wade et al., 2003; Matsushita et al., 2006; Boentje and Blinnikov, 2007). Any changes in landcover can have profound local, regional, and global consequences (Klema, 2001).

The Mediterranean region is one of the world's 18 biological hot spots (Myers et al., 2000), where important biodiversity exists, and much of that biodiversity is under danger of extinction. Mediterranean forests have endured long periods of intensive

human-induced perturbations which have exacerbated fragmentation processes and caused the appearance of forest patches immersed in matrices of humanized landscapes (Gómez-Aparicio et al., 2005). Human activities such as fire, grazing, cutting, and coppicing have shaped the Mediterranean vegetation cover and turned it into a complex assemblage of highly diverse vegetation structures (Quézel and Médail, 2003). In addition, urban encroachment is occurring in chaotic patterns in Mediterranean landscapes surrounding forests. The Mediterranean region is a mosaic-like landscape characterized by intense fragmentation (Dufour-Dror, 2002). This fragmentation has contributed to the impoverishment of Mediterranean forests and grasslands (Margaris et al., 1996). Although Mediterranean forests are considered resistant to the negative effect of fragmentation (Lazanta et al., 2006), nevertheless fragmentation is rapidly changing the landscape. Forests of the Mediterranean region have become spatially scattered and are often distributed as small mountain populations.

Throughout history, there have been cycles of forest degradation and regeneration as human pressure intensified and then receded. Vegetation regrowth following a reduction in human pressure may form a continuous shrub canopy, covering areas that had previously been bare (Seligman and Henkin, 2000). Mediterranean vegetation

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recovers quite rapidly thanks to its adaptability to human intervention (Savorai et al., 2003). However, each forest type responds differently to external pressures. One forest type will adapt to the environment, while other types could become spatially rare.

The present study examines five forest types to determine their spatial pattern of fragmentation over a 38-year period in Lebanon. The aim of this study is: (1) to estimate the deforestation rate during the 1965–2003 period, using forest map (1965), Landsat TM image (1987) and Spot 5 image (2003), (2) to assess the impact of changes of forest spatial configuration on class and landscape levels, and (3) to identify urban spatial changes with regard to the original (1965) forest patches. This research provided valuable perspective and reference on the behavior of the five forest types which could assist in future management strategies and conservation programs.

2. Materials and methods

2.1. Study area

Situated on the eastern shore of the Mediterranean Sea, Lebanon occupies the junction between Europe, Asia, and Africa and has a surface area of 1,045,200 ha. The present study was conducted on 136,318 ha in the mid-northern part of the country between 35°38'–36°21'E and 34°9'–34°22'N, including the country's highest peak, Mount Lebanon (Fig. 1). The study area extends in a horizontal section 25 km wide at the seashore and 61 km wide inland. Elevation ranges from sea level to 3088 m at a point 41 km from the coast. The topography is rough and characterized by steep slopes with an average inclination of 85 m/km. Soils are mostly of brown rendzina and terra rossa characteristics developed upon Eocene chalky limestone (Dubertret, 1953; Gêze, 1956). The climate is typically Mediterranean, with mean annual temperature ranging from 12°C inland to 19°C near the coast. Annual rainfall ranges from 900 mm in the lowlands to 1400 mm in the highlands (Plassard, 1971). Rainfall occurs mostly between October and May, with a hot and subhumid to dry summer.

2.2. GIS database

2.2.1. 1965 Data

Forest mapping in Lebanon started with the aerial mission of 1962. Consequently, the 1965 forest map is the first of its type for the country (El Husseini and Baltaxe, 1965). Since then, it has never been updated for more than 38 years. It has a spatial scale of 1:50,000 and consists of 27 sheets covering the whole country. The study area covers six sheets that were digitized using a geographic information system (GIS). Five forest types were recorded in the study area: (1) oak forest (OF), (2) pine forest (PF), (3) cedar forest (CF), (4) juniper forest (JF), and (5) cypress forest (CyF).

Since a landcover map of 1965 does not exist for the study area, urban patches were extracted from a topographic map (1:50,000 spatial scale) for the same year. Both layers (forest and urban development in 1965) were resampled to 50 m pixel size and converted to a raster grid format for landscape analysis.

2.2.2. Landcover classifications of 1987 and 2003

To achieve further understanding, image series from Landsat TM for 1987 and Spot 5 for 2003 covering the study area were acquired. The 1987 series provided an intermediate landcover dataset between 1965 and 2003, dating from about the end of the civil war.

The Landsat TM and Spot 5 series were resampled to have 50 m resolution similar to the 1965 raster map grids (Staus et al., 2002). The images were geometrically and topographically corrected. Atmospheric corrections were considered unnecessary because the final classification image is to be used for comparison purposes rather than for change detection analysis (Bernstein, 1983). Terrain elevations of 50 m pixel size were obtained through building a digital elevation model (DEM) of the study area, using 50 m equidistant contour lines. The DEM was used as input to a Lambertian Reflectance Model to apply topographic normalizations to the images (Colby, 1991).

Six classes of landcover were defined: (1) oak forest (OF), (2) pine forest (PF), (3) cedar forest (CF), (4) juniper forest (JF), (5) cypress

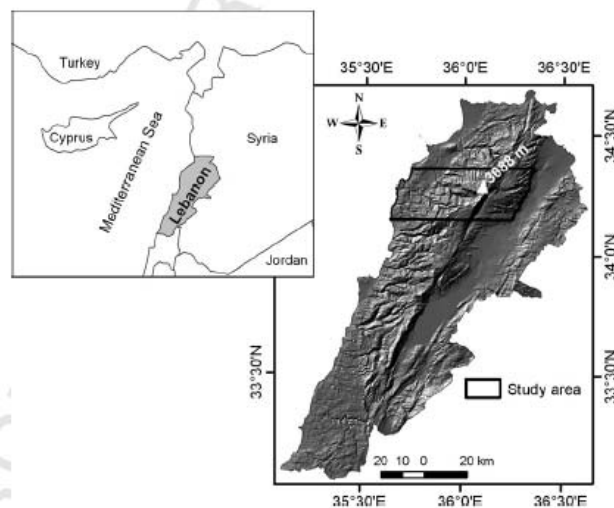


Fig. 1. Location of the study area in the north of Lebanon, traversing the mountains.

forest (CyF), and (6) non-forest areas including agricultural fields and orchards, bare soil, grass areas, and quarries.

Landcover classification was performed using landcover data from various sources such as the previously obtained 1965 landcover information for the study area. Superimposing previous data onto the satellite images assisted in performing visual interpretation and defining training sites. Fifty-three training sites were visually defined. In addition, use was made of the empirical observation that some forest types are associated with certain altitudinal ranges (Abi Saleh et al., 1996; Hoersch et al., 2002). Ground landcover data were gathered in 2003, when information could be collected from 197 locations, of which 94 points were considered to represent no change in landcover data (urban settlements, old forest growth, conservation areas, etc.). These 94 ground data points helped to determine further training sites for completing the classification of the 1987 Landsat TM images. The landcover classification map for 1987 was obtained by assigning training sites or pixels to the category determined using the criteria discussed above. This procedure is useful especially when working with earlier (belong to the past) satellite images (Cayuela et al., 2006). The entire set of ground control points (197 points) was used to classify the 2003 Spot 5 images. Visual image manipulation was performed using ERDAS IMAGINE® remote sensing software.

2.3. Accuracy assessment

Field and ground verification points (control points) are the basic elements of accuracy assessment. Observation field points are compared according to their exact location with the classified landcover classes on the map. This accuracy assessment generated a confusion matrix.

Field surveys in 2003 helped to identify 86 control points with no change in landcover and to collect 174 ground control points. The 86 points were used to construct the confusion matrix of the 1987 classified image, while the other 174 points assisted in constructing the related 2003 confusion matrix. User's accuracy, producer's accuracy and overall accuracy were calculated based on the confusion matrices (Cayuela et al., 2006).

2.4. Fragmentation and landcover change analysis

2.4.1. Landscape-level metrics

GIS layers of landcover were first converted into raster grids for the application of landscape spatial indices which were calculated using the Spatial Analyst 2.0 of ArcView version 3.2 (ESRI, 1999). Small patches (less than 5 pixels in size) within the higher spatial resolution layers (1987 and 2003) were removed (Millington et al., 2003).

Previous studies have used different landscape indices for fragmentation analysis (Imbernon and Branthomme, 2001; Li et al., 2001; Staus et al., 2002; Echeverría et al., 2006; Cayuela et al., 2006; Matsushita et al., 2006), which we chose the following: (a) patch number (NP), (b) mean patch area (MPA in ha), (c) total landscape area (TA in ha), (d) class area (CA in ha), (e) mean shape index, (f) largest patch index (LPI, % of the landscape covered by the largest patch), (g) area-weighted mean patch fractal dimension index, (h) mean proximity index (MPI), (i) mean nearest neighbor index (MNN); (j) Shannon's diversity index (SDI), (k) Shannon's evenness index (SEI), and (l) interspersed and juxtaposition index (IJI).

Number of patches (NP) and mean patch area (MPA) are computed together because they provide a direct interpretation of landscape-level fragmentation, e.g., high NP with low MPA corresponds to a highly fragmented landscape (Leitao and Ahern, 2002). For a more detailed definition of landscape indices, the reader

is referred to the FRAGSTATS user guide (McGarigal and Marks, 1995).

2.4.2. Urban changes and urban spatial configuration with regard to 1965 forest patches

The total urban area in 1965 was first compared to the urban cover of 1987 and 2003. Then we investigated urban spatial transformation and coverage changes with respect to the spatial configurations of 1965 forest patches. Two separate GIS raster layers were created, each including: (1) forest and urban patches in 1965 and (2) forest patches in 1965 and urban patches in 2003. Mean nearest-neighbor (MNN) and mean proximity (MPI) indices were computed for each layer on the landscape level. This approach helped to understand the degree of urban spread throughout the study area and how urban patches move toward areas of potential forest use. Areas of forest potential were considered to be the old forest spatial locations (1965 forest locations). This analysis measures the difference in proximity between urban and forests in 1965 and between the forests of 1965 and urban patches in 2003. The recognition of how urban areas approached original forest locations (1965) generated additional understanding of the forest changes that had occurred by 2003.

2.5. Forest regeneration

Regenerated forest patches were considered to be the new (2003) forest patches that had appeared on the outside of the 1965 forest patches (old forest locations within the landscape). For each forest type, the outside forest patches were counted within each 100 m interval, starting from the patch edges of the 1965 forests. The area in hectares was also recorded to identify the forest type with the most regenerated area. This analysis indicated the distance relationship or the proximity of regenerated forests of each forest type to the 1965 forest patches.

3. Results

3.1. Accuracy assessment

The classifications of the 1987 Landsat TM and Spot 5 images have an overall accuracy of 76% and 85% respectively (Table 1). The lower level of accuracy for the 1987 image classification is related to the larger original pixel size of the images (Mehner et al., 2004) and to the fact that the images were acquired 16 years before the field investigations in 2003. The lowest value of producer's accuracy corresponded to cedar forest, which was under-classified. The lowest value of user's accuracy was for the pine and cypress forest classes, which were overestimated in the classification. Cedar forest has a limited geographical distribution. Pine forest might contain oaks as lower layer or understory trees, resulting in a less clear spectral signature differentiation. Cypress has limited geographic distribution and underwent reforestation during the early 1990s.

3.2. Changes in landcover areas

3.2.1. Total area change of each forest type

Changes in forests and landcover information were derived following the analysis of the three raster grids of 1965, 1987, and 2003 (Fig. 2). The forest area decreased from 37,380 ha (27% of the study area) in 1965 to 27,321 ha (20%) in 2003. This corresponds to a loss of only 7% of the native forests during the period 1965–2003. Although total forest area decreased, oak forest increased from 18,335 to 20,421 ha (13–15%), cedar forest from 1059 to 1069 ha (0.7–0.8%) and cypress forest from 25 to 130 ha (0–0.1%). Among all the forest types, juniper forest showed the most dramatic decrease, from 12%

Table 1
Q4 Confusion matrix for classification of 1987 Landsat TM and 2003 Spot 5 satellite images using six categories of landcover

| Classified map | Ground control points | | | | | | | 2003 Spot 5 image | | | | | | |
|------------------------|-----------------------|----|----|----|-----|-----|-----------------|-------------------|----|----|----|-----|-----|-----------------|
| | 1987 TM image | | | | | | | | | | | | | |
| | OF | PF | CF | JF | CyF | NoF | User's accuracy | OF | PF | CF | JF | CyF | NoF | User's accuracy |
| Oak forest (OF) | 20 | 1 | 0 | 0 | 0 | 1 | 90 | 39 | 2 | 0 | 0 | 0 | 1 | 92 |
| Pine forest (PF) | 3 | 9 | 0 | 4 | 1 | 0 | 52 | 3 | 20 | 1 | 4 | 1 | 0 | 69 |
| Cedar forest (CF) | 0 | 1 | 3 | 0 | 0 | 0 | 75 | 0 | 1 | 3 | 0 | 0 | 0 | 75 |
| Juniper forest (JF) | 0 | 1 | 0 | 20 | 0 | 1 | 90 | 0 | 2 | 0 | 26 | 0 | 3 | 83 |
| Cypress forest (CyF) | 0 | 0 | 1 | 0 | 3 | 0 | 75 | 0 | 1 | 1 | 1 | 5 | 0 | 62 |
| Non forest cover (NoF) | 1 | 0 | 1 | 3 | 0 | 11 | 68 | 2 | 0 | 0 | 3 | 0 | 55 | 91 |
| Total | 24 | 12 | 5 | 28 | 4 | 13 | 86 | 44 | 26 | 5 | 34 | 6 | 59 | 174 |
| Producer's accuracy | 83 | 75 | 60 | 71 | 75 | 84 | 76 | 88 | 76 | 60 | 76 | 83 | 93 | 85 |

of the study area in 1965 to 3% in 2003. Pine forest decreased by 0.5% during the period 1965–2003. The non-forest cover increased from 73% to 80% from 1965 to 2003 (Table 2).

Annual deforestation rate was $0.2\% \text{ yr}^{-1}$ for the period from 1965 to 1987. This rate slowed to about $0\% \text{ yr}^{-1}$ during the period 1987–2003. The overall rate of deforestation is moderately low.

3.2.2. Transition matrices

Since a landcover map for 1965 does not exist, transition matrices were derived for the forest patches only, by searching inside the 1965 forest patches using landcover data from 1987 and 2003. Agriculture areas covered 7% of the oak forest and 4% of the total for-

est area in 1987. Juniper forest was mainly converted into grass area (33% of the 1965 juniper forest area). Grass was the most prominent landcover that invaded the forest area during the entire period. In total, 20% of the forest area was converted into grassland. Agriculture is the next most important landcover type that occupied the 1965 forest area, accounting for 4% of that area. Only 0.6% of the forest area was converted to urban settlements. Oak forest was the most affected by urban expansion, with changes of 1% of this forest area to urban uses (Table 3). However, the total area of oak forest increased from 1965 to 1987.

Similarly, 2003 landcover data showed that grass was the predominant landcover type to occupy 1965 forest area (22%). Agri-

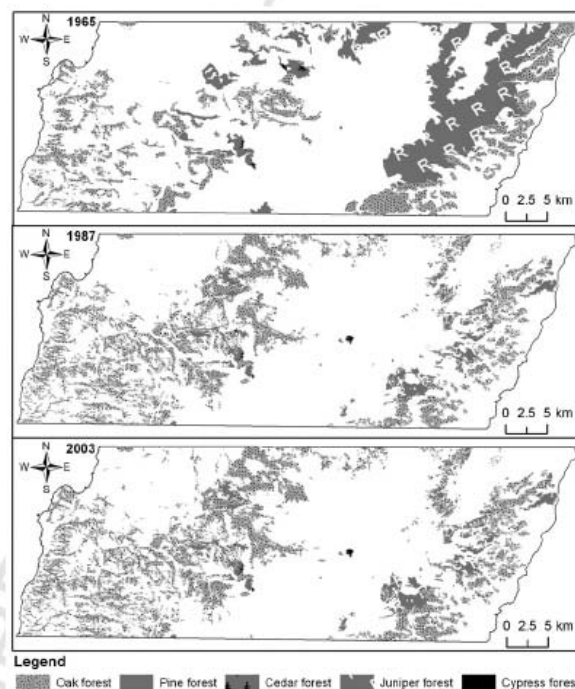


Fig. 2. Variation in the spatial configuration of forests in 1965, 1987, and 2003.

Table 2
Estimated area of landcover types (class area, CA) in 1965, 1987 and 2003 in the study area

| Land classes | 1965 | | 1987 | | 2003 | |
|--------------------|--------|----|---------|----|---------|----|
| | ha | % | ha | % | ha | % |
| Oak forest | 18,335 | 13 | 18,788 | 14 | 20,421 | 15 |
| Pine forest | 1,592 | 1 | 1,067 | 1 | 1,023 | 1 |
| Cedar forest | 1,059 | 1 | 1,048 | 1 | 1,069 | 1 |
| Juniper forest | 16,369 | 12 | 6,589 | 4 | 4,678 | 3 |
| Cypress forest | 25 | 0 | 122 | 0 | 130 | 0 |
| Non forest cover | 98,938 | 73 | 108,704 | 80 | 108,997 | 80 |
| Total forests only | 37,380 | 27 | 27,614 | 20 | 27,321 | 20 |

Table 3
Transition matrix of forest patches over the study area for the periods 1965–1987 and 1965–2003

| 1965 forests | | Agriculture (ha) | | Urban (ha) | | Grass (ha) | | Forests (ha) | | Water (ha) | | total |
|--------------|------|------------------|---|------------|---|------------|----|--------------|-----|------------|---|--------|
| | | % ^a | | % | | % | | % | | % | | |
| Oak | 1987 | 1350 | 7 | 235 | 1 | 1854 | 10 | 14,896 | 81 | 0 | 0 | 18,335 |
| | 2003 | 1651 | 9 | 300 | 2 | 1904 | 10 | 14,477 | 79 | 3 | 0 | |
| Pine | 1987 | 24 | 1 | 1 | 0 | 15 | 1 | 1,552 | 97 | 0 | 0 | 1,592 |
| | 2003 | 37 | 2 | 2 | 0 | 24 | 1 | 1,529 | 96 | 0 | 0 | |
| Cedar | 1987 | 6 | 0 | 0.1 | 0 | 101 | 9 | 951.5 | 89 | 0 | 0 | 1,059 |
| | 2003 | 7 | 0 | 0.1 | 0 | 108 | 9 | 949 | 89 | 0 | 0 | |
| Juniper | 1987 | 238 | 1 | 5 | 0 | 5515 | 33 | 10,611 | 64 | 0 | 0 | 16,369 |
| | 2003 | 273 | 2 | 8 | 0 | 6271 | 38 | 9,817 | 60 | 0 | 0 | |
| Cypress | 1987 | 0 | 0 | 0 | 0 | 0 | 0 | 25 | 100 | 0 | 0 | 25 |
| | 2003 | 0 | 0 | 0 | 0 | 0 | 0 | 25 | 100 | 0 | 0 | |
| Total | 1987 | 1618 | 4 | 241.1 | 0 | 7485 | 20 | 28,035.5 | 75 | 0 | 0 | 37,380 |
| | 2003 | 1968 | 5 | 310.1 | 0 | 8307 | 22 | 26,797 | 71 | 3 | 0 | |

^a Difference in figures is related to decimal rounding.

culture increased in the 1965 forest patches from 4% to 5% of the forest area during the period from 1987 to 2003, while urban uses increased from 0.6% to 0.8%. As a recent development, some water reservoirs had appeared inside the oak forest in 2003 (0% of the 1965 oak forest area) (Table 3). The remaining oak forest inside the 1965 forest patches was 14,477 ha, a decrease of 3858 ha from 1987.

3.2.3. Regeneration of 1965 forests

The oak forest of 1965 was found to have decreased by 21% (remained 79% of the 1965 forest patches) when only the inside of the old oak forest patches was considered, but within the overall area, oak forest showed an increase from 13% to 15% of the study area. This increase of oak forest outside the 1965 patches is related to the regeneration capability of this forest type (Lipshitz and Biger, 1990). Outside the 1965 forest patches, we searched each 100 m band starting from the edge of the patches and recorded the area of each forest type and the total number of forest patches (Fig. 3a and b). Oak forest was present in large areas (5479 ha) within the first 100 m band. Pine and cedar forest appear at 400–500 m distance only because of reforestation, with only 48 and 51 ha respectively. Oak forest occurs at distances up to 800–900 m from the 1965 forest patches. In 2003, the total number of patches that occur outside the 1965 forest patches attains 90% at 600–700 m distance. In other words, the majority of the outer patches of 2003 are located within 0–700 m distance outside the 1965 forest patches. Outer patches (on the outside of 1965 forest patches) are either regenerated or reforested, depending on the forest type.

3.2.4. Urban expansion and spatial distribution with regard to 1965 forests

Urban area in this part of Lebanon doubled from 1965 to 2003 (2473–4945 ha). Urban settlements in 2003 had penetrated 1965 forest patches at different rates depending on the forest type. Oak forest was the most affected by urban expansion, where 300 ha of forest area was converted to urban settlements (Table 3).

We investigated changes in urban spatial distribution at the landscape level with regard to 1965 forest patch locations. The mean nearest neighbor and mean proximity indices decreased from 632 to 481 m and from 50.98 to 44.18 respectively. The approach rate of urban settlements toward forests is 4 m yr^{-1} . The calculation was performed on two landscape layers: (1) forest patches of 1965 with urban areas of 1965, and (2) forest areas of 1965 with urban areas of 2003. Mean patch area decreased from 219 (forest patches of 1965 alone) to 98 (forest with urban areas of 1965). The same index decreased from 98 to 82 when placing forests of 1965 with

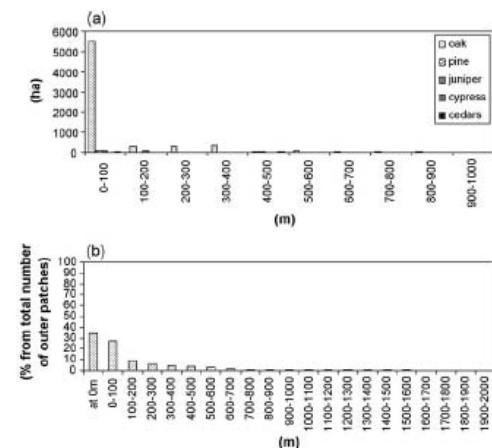


Fig. 3. (a) Area in hectares of 2003 patches located outside 1965 forest patches, (b) Number of patches (%) in 2003 located in each 100 m distance band outside the 1965 forest patches.

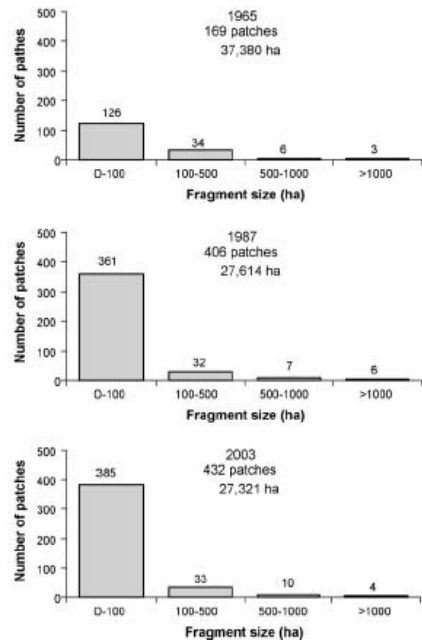


Fig. 4. Number of forest patches with relation to patch area for the three years 1965, 1987, and 2003.

urban areas of 2003. This analysis provided a greater understanding of how urban areas approached the forests of 1965.

3.3. Forest fragmentation

The number of landscape forest patches has changed from 169 to 409 between 1965 and 1987 and reached 432 in 2003 (Fig. 4). This corresponds to an annual increase in the number of forest fragments of 11% in 1965–1987 and 2% in 1987–2003. Mean patch size decreased from 219 to 84 ha during 1965–1987 and from 84 to 70 ha during 1987–2003. The change rates of the patch size are 6 and 0.9 ha yr⁻¹ during the two periods.

Although mean patch size was the highest in 1965, 7% of the forest area was found in patches of less than 100 ha (Fig. 4). The remaining forests occurred 21% in patches between 100 and 500 ha, 3% in patches between 500 and 1000 ha, and 2% in patches >1000 ha. The number of small patches, between 0 and 100 ha, tripled during the period from 1965 to 2003 (from 126 to 385 patches). The number of small patches (0–100 ha) increased to reach 88% and 89% of the total patches in 1987 and 2003 respectively. Other patch

sizes showed a stable number of patches throughout the time periods.

The landscape is subjected to fragmentation when the number of patches increases and the mean patch area decreases. Both Shannon's diversity and Shannon's evenness indices decreased in the two periods, which indicates a lesser proportional distribution of area among patch types or the dominance of the landscape by a single patch type (Table 4).

The decrease in mean patch area was associated with a reduction in the largest-patch index by 32% (from 15% to 10%) from 1965 to 2003. The mean nearest neighbor index decreased as a result of the increase in the number of patches. This combination of landscape spatial reconfigurations is attributed to fragmentation of larger patches and not to a higher rate of aggregation of patches. In addition, the interspersed and juxtaposition index (IJI) decreased, indicating that the spatial distribution of adjacencies among patch types became increasingly uneven. This result was related to fragmentation of larger patches and to dominance of one patch type.

At the class level (forest type), patch number increased with the decrease in mean patch area in both periods (Fig. 5). For juniper forest, the mean nearest neighbor and juxtaposition indices decreased from about 3000 to 500 m and 20 to 5 respectively, which indicate the appearance of many small patches with uneven distribution during both periods. Oak forest showed a minor decrease in the mean nearest neighbor index (from 354 to 300 m) while the IJI increased (from 58 to 77), indicating the presence of more patches with an even distribution. Pine and cedar forest showed similar trends with increases in MNN and decreases in IJI. Cypress forest experienced increases in both MNN and IJI. Pine, cedar, and cypress forests were reforested in different locations.

Area-weighted mean patch fractal dimension for all forest types showed a change of less than 0.1 throughout the study period. The shape complexity decreased during the entire period. The simplicity of patch shape was the highest for juniper forests.

4. Discussion

Along the twentieth century forest of Mount Lebanon had undergone major spatial configuration changes that require detailed investigations. Technological advances, such as remote sensing data, fulfill the need of executing forest spatial pattern information.

4.1. Accuracy of the results

Remote sensing data are becoming the basis of almost any land-cover change research study. However, imprecision in the results is always a concern (Foody, 2002). Various errors can accumulate in the results as obtained. Differences of spatial scale among data sources remain the main cause of inaccuracy in results. Several approaches can be used to reduce errors in landscape change analysis using remote sensing data. Reduction of image spatial resolution and generalization (resampling models) moderately reduce errors for landscape analysis studies (Brown et al., 2000).

Table 4
Landscape metrics for the three observation years

| Year | TA (ha) | LPI (%) | NP | MPA (ha) | AWMPFD | MNN (m) | MPI | SDI | SEI | IJI |
|------|---------|---------|-----|----------|--------|---------|--------|------|------|-------|
| 1965 | 136,318 | 15 | 169 | 219 | 1.14 | 600 | 78.29 | 0.95 | 0.59 | 49.48 |
| 1987 | 136,318 | 10 | 406 | 84 | 1.16 | 524 | 195.34 | 0.87 | 0.43 | 49.20 |
| 2003 | 136,318 | 10 | 432 | 70 | 1.18 | 492 | 225.15 | 0.81 | 0.41 | 48.13 |

TA, total landscape area; LPI, largest patch index; NP, number of patches; MPA, mean patch area; AWMPFD, area weighted mean patch fractal dimension; MNN, mean nearest neighbor; MPI, mean proximity index; SDI, Shannon diversity index; SEI, Shannon evenness index; IJI, interspersed and juxtaposition index.

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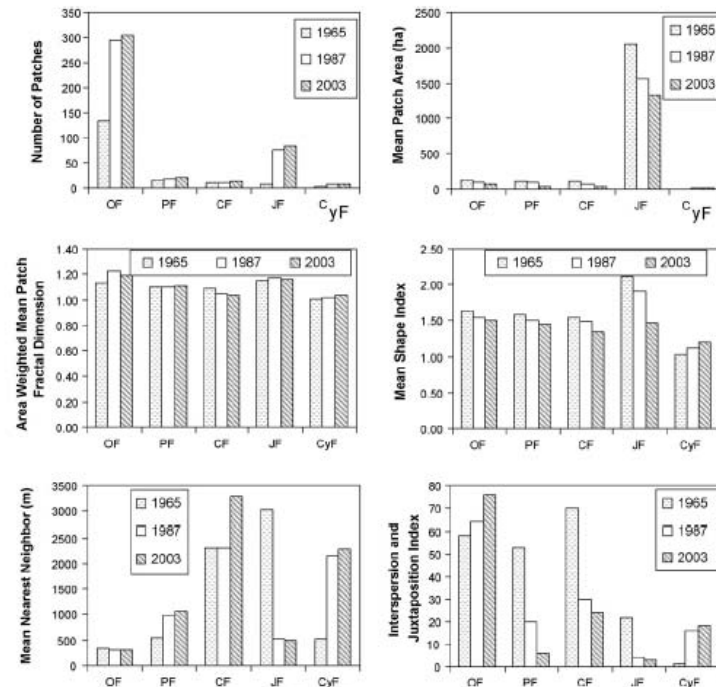


Fig. 5. Comparison of class-level landscape indices.

The low classification accuracy of some forest types is related to stages of succession for forest present in the study area (Cayuela et al., 2006; Püssa et al., 2006). Pine forest in our research area is found either as pure stands of pine trees or as pine mixed with an understory of oak trees.

4.2. Forest loss

Deforestation rates in Lebanon during the last four decades have not been considered in previous studies. The annual rate of forest loss showed a decrease of 10-fold (from 0.2% to about 0%) between the first period (1965–1987) and the second one (1987–2003). The major difference between these two periods is the end of the civil war (1975–1989) when people lost interest in forests and started abandoning agricultural lands. During the first period, people left the cities to obtain shelter from the war, and at that time the forest underwent most of its loss.

Among the main causes of deforestation are urban settlements and land conversion to agriculture. Although oak forest is the main forest type that has been subjected to invasion by human settlements and agriculture, it showed an increase in total area (Table 2). This type of forest occurs in areas of relatively low altitude where human intervention can be expected to be more intensive (Abi Saleh et al., 1996). Cedar forest increased in area to a limited extent, indicating the conservation of this tree and a limited amount of reforestation. This result goes in agreement with the area sub-

jected to reforestation published by the Ministry of Environment in Lebanon (NRP, 2001). Cypress forest also increased its limited area. Juniper forest decreased almost four-fold and was mainly converted to grasslands.

The main reason for the high deforestation rate in the first period is the dramatic loss of juniper forest. People changed their usage of the juniper tree in the late 1960s and early 1970s, when it came to be used only as firewood. Juniper forest was used excessively for home roofing in villages at the beginning of the first period. Oak forest has always been used for charcoal production and as firewood. Agriculture replaced most of the 1965 oak forest, but this tree has a strong regeneration capability in abandoned lands (Savorai et al., 2003), which caused the appearance of new oak forest outside the 1965 forest patches. The majority of the regenerated oak forest patches were found in the first 200 m outside the 1965 forest patches (Fig. 3a and b). This spatial relation or proximity to older forest patches demonstrates that when human pressure is removed, oak forest prevails in new regeneration areas.

The 7% decrease in forest area during the entire period was distributed differently among forests, i.e., some forest types might disappear while others might show an increase in area. In an area that is characterized by a number of forest types, it would be misleading to investigate the forest as a whole (all forest types combined into one forest class). A landscape analysis alone would be insufficient in such a case and would need to be followed by a class-level analysis.

4.3. Urban expansion

One of the main causes of deforestation is expansion of urban settlements which replace forest areas. Urban area in this part of Lebanon has doubled during the study period, which puts the forest under risk of exploitation for agriculture, quarries, water storage reservoirs, and other uses. Oak forest is the most highly affected by urban expansion because of its geographical distribution at lower altitudes (for forest-altitude distribution see Abi Saleh et al., 1996).

To investigate how urban settlements approached the original locations of forests (the 1965 forest patch spatial configuration), it was assumed that the forests of 1965 stayed in place and the urban settlements changed their locations, approaching forest areas. The mean nearest neighbor and proximity indices were calculated to quantify the degree of proximity between new urban extensions and old forest locations. This method reflects the degree of disturbance that urban expansion is exerting on forests. It also provided insight for the chaotic nature of urban growth that is happening without considering the forest ecological requirements and the presence of potential forest lands. This will lead to the appearance of more small forest fragments surrounded by urban settlements.

4.4. Forest fragmentation

Forests covered 27% in 1965 and 20% in 2003 of the total landscape area. This value is similar to those obtained for other landscapes exhibiting fragmented urban and agricultural land uses at the Mediterranean and in different geographical locations (Bielsa et al., 2005; García et al., 2005; Mouillot et al., 2005; Matsushita et al., 2006). The spatial configuration of patches demonstrated the degree of fragmentation at the landscape level. The increase in number of patches and decrease of mean patch area indicated a high level of fragmentation. The decrease in the largest patch index was followed by an increase in the number of small fragments (0–100 ha patches) (Table 4 and Fig. 5), indicating an important trend towards forest fragmentation.

The majority of patches observed since 1965 have 0–100 ha in size. The increase in the number of patches in this size range in both periods indicated isolation of patches and further landscape fragmentation. The numbers of larger patches (100–500, 500–1000 and > 1000 ha) remained unchanged during the study period. A continuous forest cover did not dominate the landscape (largest patch index 15% in 1965 and 10% in 2003), and large forest patches were and remained very few. Landscape-level mean nearest neighbor index had decreased with relation to the increase in the number of small patches (0–100 ha), due to fragmentation of large patches and not to a better degree of connectivity between patches. The landscape showed an increasing trend in number of forest patches and a decrease in mean patch size. However, mean nearest neighbor index decreased, which would indicate that the landscape is exhibiting a tendency towards better connectivity. In fact, this MNN decrease is related to further fragmentation of forest patches, both large and small. This could also be reflected by the increase in mean proximity index which more than doubled during the study period (Cayuela et al., 2006).

Shape complexity, measured by area-weighted mean patch fractal dimension, was mostly regular throughout both periods. This observation is consistent with a man-made structure of plantations located in agricultural areas in addition to urban influence (Bielsa et al., 2005).

4.5. Forest regeneration

Since some forest types showed an increase in their coverage area, it is logical to search for regenerated forests. We considered

that forest regeneration occurred on the outside of the 1965 forest patches. On the outside of the 1965 forest patches, each 100 m band was searched for its forest occurrence. Oak forests appeared mainly within the first two bands. The regenerated oaks had direct geographical contact with previous forest patches. Oaks regenerate on abandoned agricultural lands that surround forests or expanded on neighboring grasslands. Oak forest expands over the first 400 m which demonstrate how this forest might rapidly cover new areas.

5. Conclusions

This research was able to quantify changes of the forest spatial patterns in Mount Lebanon and in assessing the urban expansion rate toward forest potential areas. Remote sensing data were used together with spatial pattern analysis which is rarely applied for Mediterranean landscapes. Remote-sensing data continue to be the fastest and most effective tool to provide vital information for forest managers. Landscape and class level (forest type) spatial analysis appeared to represent important set of information permanently required for Lebanese forests. Landscape pattern indices are used mainly to quantify the degree of forest fragmentation. This research presents different manner utilization of such indices. Landscape indices clarify the danger that urban expansion is exerting on the forest areas. The study area is strongly influenced by chaotic urban expansion which is rapidly approached existed forests and potential forest lands.

Human interest in a forest type changes throughout history. Juniper forest has been drastically lost. Oak forest is able to overcome deforestation through regeneration in newly abandoned lands. However, oak forest is facing the problem of decreasing mean patch area and increasing patch number. Forests continue to face high risk of fragmentation. Although the deforestation rate has decreased, forest fragmentation continued to increase during the second period. The study area therefore requires energetic conservation efforts which take into consideration the spatial or geographical distribution of each forest type.

Uncited references

Daley et al. (1997), Foody and Hill (1996) and Hall (1984).

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References

- Abi Saleh, B., Nasser, N., Hanna, R., Safi, N., Safi, S., Tohmé, H., 1996. Etude de la diversité biologique du Liban. Ministère de l'Agriculture, Liban. PNUE. Projet GF/6105.92.72. Publication No. 3, p. 146.
- Bernstein, R., 1983. Image geometry and rectification. In: Colwell, R.N. (Ed.), *Manual of Remote Sensing*. American Society of Photogrammetry, Falls Church, Virginia, pp. 873–922 (Chapter 21).
- Bielsa, I., Pons, X., Bunce, B., 2005. Agricultural abandonment in the North Eastern Iberian Peninsula: the use of basic landscape metrics to support planning. *J. Environ. Plan. Manage.* 48 (1), 85–102.
- Boentje, J.P., Blinnikov, M.S., 2007. Post-Soviet forest fragmentation and loss in the Green Belt around Moscow, Russia (1991–2001): a remote sensing perspective. *Landsc. Urban Plan.* 82, 208–221.
- Brown, D.G., Duh, J.D., Drzyzga, S.A., 2000. Fragmentation change using North American landscape characterization (NALC) data. *Remote Sens. Environ.* 71, 106–117.
- Cayuela, L., Rey Benayas, J.M., Echeverría, C., 2006. Clearance and fragmentation of tropical montane forests in the Highlands of Chiapas, Mexico (1975–2000). *Forest Ecol. Manage.* 226, 208–218.
- Colby, J.D., 1991. Topographic normalization in rugged terrain. *Photogram. Eng. Remote Sens.* 57 (5), 531–537.

- Daley, N., Goodenough, D.G., Bhogal, A.S., Bradley, Q., Yin, Z., 1997. Comparing raster and object generalization. *Geosci. Remote Sens.* 2, 677–679.
- Dubertret, L., 1953. Carte géologique de la Syrie et du Liban au 1/50,000^e, 21 feuilles avec notices explicatives. République Libanaise, Ministère des Travaux Publics, L'imprimerie Catholique, Beyrouth, p. 66.
- Dufour-Dror, J.M., 2002. A quantitative classification on Mediterranean mosaic landscapes. *J. Mediterranean Ecol.* 3, 3–12.
- Echeverría, C., Coones, D., Salas, J., Rey Benayas, J.M., Lara, A., Newton, A., 2006. Rapid deforestation and fragmentation of Chilean temperate forests. *Biol. Conserv.* Available online: <http://www.aseanenvironment.info/Abstract/41012806.pdf>.
- El Hussein, K., Baltaxi, R., 1965. Forest type map at 1/50,000 scale. Forestry Education, Training and Research Project, Green plan, Lebanon. United Nations Special Fund/FAO.
- Foody, G.M., Hill, R.A., 1996. Classification of tropical forest classes from Landsat TM data. *Int. J. Remote Sens.* 17, 2353–2367.
- García, D., Quevedo, M., Ramón Obeso, J., Abajo, A., 2005. Fragmentation patterns and protection of montane forest in cantabrian range (NW Spain). *Forest Ecol. Manage.* 208, 29–43.
- Gèze, B., 1956. Carte de reconnaissance des sols du Liban au 1/200,000^e. République Libanaise, Ministère de l'Agriculture, Direction de l'Enseignement et la Vulgarisation, Station Agronomique Libano-Française. Notice Explicative, p. 52.
- Gómez-Aparicio, L.F., Valladares, L.F., Zamora, R., Quero, J.L., 2005. Response of tree seedlings to the abiotic heterogeneity generated by nurse shrubs: an experimental approach at different scales. *Ecography* 28, 757–768.
- Hall, J.B., 1984. *Juniperus excelsa* in Africa: a biogeographical study of an Afromontane tree. *J. Biogeogr.* 11, 47–61.
- Hoersch, B., Braun, G., Schmidt, U., 2002. Relation between landform and vegetation in alpine regions of Wallis, Switzerland. A multiscale remote sensing and GIS approach. *Comput. Environ. Urban Syst.* 26, 113–139.
- Imbernon, J., Branthomme, A., 2001. Characterization of landscape patterns of deforestation in tropical rain forests. *Int. J. Remote Sens.* 22, 1753–1765.
- Klemas, V.V., 2001. Remote sensing of landscape-level coastal environmental indicators. *Environ. Manage.* 27, 47–57.
- Laurance, W.F., 1999. Reflections on the tropical deforestation crisis. *Biol. Conserv.* 91, 109–117.
- Lazanta, T., Gozález-Hidalgo, J.C., Vicente-Serrano, S.M., Sferi, E., 2006. Using landscape ecology to evaluate an alternative management scenario in abandoned Mediterranean mountain area. *Landscape Urban Plan.* 78, 101–114.
- Leitao, A.B., Aherm, J., 2002. Applying landscape ecological concepts and metrics in sustainable landscape planning. *Landscape Urban Plan.* 59, 65–93.
- Li, X., Lu, L., Cheng, G.D., Xiao, H.L., 2001. Quantifying landscape structure of the Heihe River Basin, north-west China using FRAGSTATS. *J. Arid Environ.* 48, 521–535.
- Lipshitz, N., Bigger, G., 1990. Dominance of *Quercus calliprinos* (Kermes oak)-*Pistacia palaestina* (Terebinth) association in the Mediterranean territory of Eretz Israel during antiquity. *J. Veg. Sci.* 1, 67–70.
- Margaris, N.S., Koutsidou, E., Giourga, Ch., 1996. Changes in traditional Mediterranean land-use systems. In: Brandt, C.J., Thomas, J.B. (Eds.), *Mediterranean Desertification and Land Use*. Wiley, Chichester, pp. 29–42.
- Matsumoto, B., Xu, M., Fukushima, T., 2006. Characterizing the changes in landscape structure in Lake Kasumigaura Basin, Japan using a high-quality GIS dataset. *Landscape Urban Plan.* 78, 241–250.
- McGarigal, K., Marks, B.J., 1995. FRAGSTATS: Spatial Pattern Analysis Program for Quantifying Landscape Structure. Forest Science Department, Oregon State University, Corvallis.
- Mehner, H., Cutler, M., Fairbairn, D., Thompson, G., 2004. Remote sensing of upland vegetation: the potential resolution satellite sensors. *Global Ecol. Biogeogr.* 13, 359–369.
- Millington, A.C., Velez-Liendo, X.M., Bradley, A.V., 2003. Scale dependence in multi-temporal mapping of forest fragmentation in Bolivia: implications for explaining temporal trends in landscape ecology and applications to biodiversity conservation. *Photogram. Remote Sens.* 57, 289–299.
- Mouillot, F., Ratte, J.P., Joffre, R., Mouillot, D., Rambal, S., 2005. Long-term forest dynamic after land abandonment in a fire prone Mediterranean landscape (central Corsica, France). *Landscape Ecol.* 20, 101–112.
- Myers, N., Mittermeir, R.A.M., da Fonseca, C.A.B., Kent, J., 2000. Biodiversity hotspots for conservation priorities. *Nature* 403, 853–858.
- NRP, 2001. The National Reforestation Plan. Reforestation project on the national level, Ministry of Environment, Lebanon. <http://www.moe.gov.lb/Reforestation/National+Reforestation+Plan.htm>.
- Plassard, J., 1971. Carte pluviométrique du Liban à l'échelle de 1/200,000. République Libanaise, Ministère des travaux publics, Direction Générale de l'Aviation Civile.
- Püssa, K., Liira, J., Peterson, U., 2006. The effect of successional age and forest type on radiance of forest clear-cut communities. *Agric. Forest Sci. Geogr. J.* 20, 79–87.
- Quézel, P., Médail, F., 2003. *Ecologie et biogéographie des forêts du bassin méditerranéen*. Editions scientifiques et médicales Elsevier SAS, p. 571.
- Savorai, T., Shoshany, M., Perevolotsky, A., 2003. Mediterranean rangeland response to human intervention: a remote sensing and GIS study. *J. Mediterranean Ecol.* 4, 3–11.
- Seligman, N.G., Henkin, Z., 2000. Regeneration of a dominant Mediterranean dwarf-shrub after fire. *J. Veg. Sci.* 11, 893–902.
- Staus, N., Stritzholt, J., Dellasala, D., Robinson, R., 2002. Rate and patterns of forest disturbance in the Klamath-siskiyou ecoregion, USA, between 1972 and 1992. *Landscape Ecol.* 17, 455–470.
- Tellería, J.L., Baquero, R., Santos, T., 2003. Effects of forest fragmentation on European birds: implications of regional differences in species richness. *J. Biogeogr.* 30, 621–628.
- Wade, T.G., Ritters, K.H., Wickham, J.D., Jones, K.B., 2003. Distribution and causes of global forest fragmentation. *Conserv. Ecol.* 7 (2), 7.

Article 3.

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**Title: Analysis of Eastern Mediterranean oak forests over the period
1965-2003 using landscape indices on a patch basis**

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Abstract

Although Eastern Mediterranean forests have been exploited for many years, the changing trends in the past 40 years require detailed investigations. Forests in the coastal zone of Lebanon are witnessing major changes mainly because of chaotic urbanization. The study area at the coastal zone of Lebanon has 96% of its forest cover under oak coppice. The aim of this study is to investigate the applicability of landscape indices on oak forests especially their ability to detect changes between 1965 and 2003. It uses forest canopy closure as another indicator of forest destruction.

The 1965 forest map was first checked for its accuracy before being used to extract patch delineations and canopy closures, Landcover types for 2003 were obtained by classifying a SPOT 5 satellite image. FRAGSTATS software was utilized on the 1965 map on a patch basis to calculate patch shapes and sizes. These indices and canopy closures data were investigated for correlation purposes with patterns of forest loss. The edge distances between forest patches in 1965 and new forest patches in 2003 were computed to analyze regeneration processes.

Results show that although older forest patches have shown a 48% loss in area, total forest area reached 83%. Abandoned agricultural lands have become new forest. Smaller forest patches (<40 ha) showed greater losses than large ones. Small and open forest patches recorded greater loss than large and dense patches. Shape indices show no correlation with forest loss. Clearance for agriculture covered 30% of the preexisting forests, while urban developments accounted for just 4% of forest loss.

This research highlights the great need for comprehensive studies of forests using landscape analyses. Such analyses help managers develop practical and relevant conservation measures.

Keywords: Patch shape, patch size, canopy closure, oak forest, remote sensing, Spot 5.

1. Introduction

The Mediterranean region represents an enormous challenge for scientists and land managers because of its size, physical complexity and geological and anthropological history (Blondel and Aronson, 1995). Forests in this region have been intensively exploited throughout history (Verlaque et al., 1997) and have experienced a close interrelation with human activities for more than 10,000 years (Pons and Quézel, 1985). These forests represent various stages of the regressive succession of the original forest. The dynamics of the natural vegetation in most Mediterranean landscapes can be described as a shifting mosaic of patches at different stages of development (Kruger et al., 1986) that reflect local disturbances (Henkin et al., 1998).

Oak forests are the major forests of the region; they have existed in the Mediterranean region since the early Miocene (Suc, 1984). Thus, the degradation and extinction of such forests have been caused mainly by human intervention rather than by climate changes (Pons and Quézel, 1998).

Historically, oak forests also dominated large portions of tropical and subtropical highlands, whereas today they are severely fragmented because of land conversion to agricultural use and the development of settlements combined with tree logging (Asbjornsen et al., 2004). Fragmentation is a major threat to most forest communities in the Mediterranean region, even though they are considered to be more resistant to the negative effect of fragmentation than the tropical forests (Quézel and Médail, 2003; Lazanta et al., 2006). Nevertheless, the regeneration of natural forests may occur once artificial stresses have been removed (Savorai et al., 2003). Thornes (1990) noted that the

critical forest cover required to ensure effective soil protection during regeneration is close to 30% in the Mediterranean region. Therefore, landcover density is an important factor that should be considered when investigating forest changes.

More attention must be given to the littoral parts of the Mediterranean region, as the natural resources of these areas are in fragile state because of intensive agricultural practices and urbanization (Médail and Loisels, 1998). Accordingly, monitoring the changes in the Mediterranean landscapes is required to enable land managers to devise effective conservation strategies. However, land managers also require data from which they can assess forest health, formulate policy decisions, and generate management plans (Sader et al., 2003). Forest investigators have taken advantage of technological advances; aerial photography, for example has been used with great success for mapping and undertaking forest inventories (Franklin et al., 2005). Remotely sensed imageries offer additional important possibilities and valuable data (multi-temporal and multi-spectral), especially with the increased accuracy of satellite images to high spatial resolution (less than 1 m pixel size). Such data have been used to study the impact of human activity on degradation processes (Zhang and Guindon, 2005). Therefore, studies of landuse changes basically rely on information extracted from remote sensing data.

A number of landscape metrics have been developed in a GIS environment to quantify and monitor changes in landcover. This analytical approach adds understanding to the development of the monitoring of progressive changes to forest patches (de Val et al., 2006). As an example, small isolated forest patches are more susceptible to external disturbances than large ones (Lefèvre, 2004; Estevan et al., 2007).

As is the case of many forests around the world, oak forests on the western slope of Mount Lebanon (coastal zone) have experienced environmental pressure for many years as various changes in land use have occurred (MoE-LEDO, 2001). Although urban encroachment is currently affecting the littoral zone (Zahreddine et al., 2004), areas of abandoned agricultural lands have provided opportunities for re-establishing new forests.

While many studies have used landscape indices to predict future trends and the risk of changes in forest ecosystems (Honnay et al., 2003), few studies have focused on how landscape indices are correlated to real changes (Hulshoff, 1995). We researched the value of using landscape indices to forest changes as they have rarely been applied to Mediterranean forests (Carrabou et al., 1998). The aim of this paper is to use the landscape indices to predict trends in forest changes. Forest cover density was also used as another index because an oak forest of the Mediterranean region changes from low to high cover density if protected. In addition, another approach of analysis was also developed in monitoring forest changes by focusing on the inside and outside of forest patches. Thus, this paper also examines the patch size, shape, and canopy closure of older forest patches. It considers the correlation of such indices with changes in forest distribution. As a typical example, Mediterranean oak forests at the northern part of coastal Lebanon were considered. A 1965 forest map was used as base data to calculate the indices described above.

2. Materials and methods

2.1 Study area

Situated on the eastern shore of the Mediterranean Sea, Lebanon occupies the junction between Europe, Asia and Africa, and has a surface area of 1,045,200 ha. The present study was conducted on a 41,433 ha area in the mid-northern part of the country between 35°38' and 35°53'E and 34°8' and 34°22'N (Fig. 1). The study area includes a 24 km coastal section and a maximum altitude of 1700 m at a point 20 km from the coast. The area is characterized by steep sloping land with an average slope gradient of approximately 85 m/km. It occupied mainly brown rendzina and terra rossa soils developed upon Eocene chalky limestone (Dubertret, 1953; Gèze, 1956). The climate is typically Mediterranean with a mean annual temperature of 19 °C at an altitude of 700 m. Annual rainfall ranges from 900 mm in the lowlands to 1400 mm in the highlands (Plassard, 1971). Rainfall mostly occurs from October to May, with a hot and subhumid to humid summer.

Oak forests in the study area consist mainly of *Quercus calliprinos* and *Ceratonia siliqua* (Zohary, 1973; Abi Saleh et al., 1996). Although, *Q. calliprinos* (in Europe it is known as *Q. coccifera*) are generally around 3 m in height in these forest areas, this tree grows to heights in excess of 20 m when provided with favorable environmental conditions (Mouterde, 1966). The tree is well adapted to the Eastern Mediterranean environment because it is drought resistant (Salleo et al., 2002). Economically, *Q. calliprinos* is an important source for charcoal production in Lebanon.

2.2. Methodology framework

This study investigates changes in forest (oak coppice) spatial structure between 1965 and 2003. Oak coppice (shrubs) forests might range from less than 1 m to a maximum of 2 m in tree height. Data on forest spatial characteristics were extracted from an existing forest map of 1965 and from classified Spot 5 satellite imagery of 2003.

Qualitative and quantitative spatial patch characteristics of 1965 were tested for their possible relation to changes that occurred in 2003. On the 1965 forest map, canopy closures (clear forests: 10% to 30% cover; dense forest: >30% cover) for each forest patch, patch size and patch shape were used, as they might verify (relate to) changes that occurred in forests in 2003. The changed matrix of landuse between forest patches of 1965 (only inside the 1965 forest patches) and the 2003 landcover was also investigated. Outside the 1965 forest patches (outside the patch border), the 2003 forests were counted as regenerated or new forests.

Canopy closure of 1965 forest patches was used as a qualitative index and compared to canopy closure of forests in 2003. For example, a dense forest patch (>30% forest coverage) in 1965 might be changed into an open (clear: 10 to 30% forest coverage) forest patch in 2003.

2.3. Characteristics of forests in 1965

Forest mapping in Lebanon started with the air-borne mission of 1962 that acquired black and white aerial photos of 1/25,000 spatial scale. The 1965 forest map is the

country's first forest map and is the outcome of visual and stereoscopic interpretations of the aerial photos and field visits (El Hussein and Baltax, 1965). It has a spatial scale of 1:50,000 and consists of 27 sheets covering the whole country. The study area constitutes 2/27 sheets that were digitized using a geographic information system (GIS). One hundred and seventy-one forest patches were delineated by two different types of canopy closure (clear and dense) of oak coppice (*Quercus* spp.) (Fig. 2a). At the study area, oak coppices have important phytosociology such as *Myrtus communis*, *Calycotome villosa*, etc (for complete list of the plants refer to Abi Saleh, 1978). Other forest types were discarded due to their limited spatial distribution (Table 1). The 1965 forest map has 0.25 ha (50x50 m) as the smallest patch area which was the smallest forest patch size to be considered in the study.

The vector layer of the 1965 forest map was converted to raster format of 25 m pixel size in order to facilitate detailed analysis, although the minimum distance mapped is 50 m. Consequently, a forest patch had two categories: 1) being larger than the minimum mappable unit and 2) having oak coppice showing both types of canopy closure. A layer of 25 m pixel size keeps the small patches of 0.25 ha to the correct size, even if they fall on the boundary between 4 pixels.

2.4. Accuracy of the 1965 forest map

Accuracy of the 1965 forest map was verified through examining 55 forest patches on the available aerial photos. The overall accuracy of the map was visually investigated

using GIS facilities. Forest patches were overlaid and matched to the aerial photos. The forest cover density was also investigated on the aerial photos (Fig. 3).

2.5. Landscape indices for 1965 forests

The spatial characteristics of the 1965 forests were investigated in terms of their patch size, patch shape and canopy closures. Each forest polygon that exists on the 1965 forest map is considered as a forest patch. The smallest patch (0.25 ha) was the size of the minimum mappable unit on the map. Patch size was counted as the surface area of a patch in hectares (Schumaker, 1996), while patch shape was considered the degree of shape complexity that was calculated by the Mean Patch Fractal Dimension (MPFD). The MPFD measures the complexity of a patch shape compared to a standard shape of the same size, and is widely applicable in landscape ecological research over a wide range of scales (Krummel et al., 1987; Ripple et al., 1991). The MPFD is based on the perimeter-area relationship, and ranges from values of 1 to 2. Values of 1 indicate shapes with simple perimeters, while values of 2 indicate complex shapes (Hargis et al., 1998). The MPFD was calculated using the following equation, which was installed as a FRAGSTATS extension for ArcView (ESRI, 1996a,b) (Rempel et al., 1999):

$$P = kA^{MPFD/2} \text{ (McCarigal and Marks, 1995)}$$

where P and A are the perimeter and area of the patches, respectively, and k is a parameter that correlates the perimeter of a shape to the square root of the area. For example, for a square, $k = 4$, while for a circle, $k = 1.264$, and for a hexagon, $k = 3.72$. Canopy closure is an important component in characterizing a landscape, as it describes the degree of degradation in a forest patch (Rikimaru et al., 1999).

2.6. Landcover map for 2003

The spatial resolution of the used satellite image (Spot 5) is 10 m pixel size. The image was resampled to reach a 50 m pixel size, using convolution filtering. A window of 5x5 pixels moved across the image (the mathematical explanations about convolution extend by the ERDAS Field GuideTM of the remote sensing software ERDAS IMAGINE®) and the average digital number (DN) value of each window was resampled into 50 m pixel size. This pixel size renders the satellite image to be comparable to the raster format for the 1965 forest map.

The landcover map for 2003 was constructed by classifying a multispectral Spot 5 satellite image (Fig. 2b). The image was acquired by an HRG 1 instrument upon Spot 5, with green, red, and near infrared bands at 10 m spatial resolution and the mid infrared band at 20 m resolution. The image was preprocessed and manipulated using ERDAS IMAGINE (www.erdas.com) remote sensing software.

In order to realize a maximum likelihood supervised classification, 214 training sites distributed over the entire area were surveyed. During the field survey, additional 216 ground truth sites were collected to determine the accuracy of the classification.

Density of the forest cover was differentiated through the training sites used for classification of the image. Seven landcover types were defined as follows (Fig. 4): clear forests (10% to 30%), dense forests (>30%), agriculture (crops or horticulture), grass, urban (settlements plus other concrete structures), quarry and water (very limited area).

2.7. Comparison of forests between 1965 and 2003

Comparison of the 2003 landcover map with the 1965 forest map was undertaken in a GIS environment using ArcGIS 9.2 software (ESRI). A change matrix was investigated within (inside the limits) patch limits of the 1965 forests, through superimposing the 2003 landcover map upon the 1965 forest map. An outside forest patch was considered as those forests of 2003 that were found to be outside the limits of the 1965 forest patches, even if it was a continuation of the patch from inside to outside.

Inside (within) and outside patch analysis offers the possibility of acquiring detailed tracing of the forest spatial changes. Landscape analyses studies usually concentrate on the spatial configuration changes that have occurred over the entire investigated landscape. This landscape analysis provides important information about the spatial configuration characteristics changes which adds to those extracted by using landscape indices (Cayuela *et al.*, 2006). The applied (inside-outside) approach presents important forest loss information on the basis of each patch and the subsequent landcover changes inside the patches. The outside patch forests approach provided information about forest regrowth and regeneration.

A statistical method was developed to help understand how patches of new forests grew in relation to existing ones. Edge distances were computed between new forest (outside) patches identified in 2003 and 1965 forest patches; this revealed how different the new patches of 2003 are in relation to forest patches that existed in 1965. New forest patches that share edges with old forests were counted as the 0 m distance.

3. Results

3.1. Accuracy of the used data

Determining the accuracy of the 1965 forest map (base map in this research) was necessary, as it is the base data source used for the study (Fig. 5). The visual comparison of the 55 forest patches revealed accurate delineation of the forests. Each forest patch delineated an area of woods on the matched aerial photo. Another example was considered that shows the 1965 forest map with its underlying aerial photo and the corresponding SPOT 5 satellite image (Fig. 6).

The ground truth points checked the classification accuracy of the satellite image. These points were collected as sites or areas. The sites were drawn on a printout of the satellite image with false color composite (R = green band, G = red band and B = near infrared band). Homogeneous areas were visually detected on the satellite image, using field data. These sites were converted to polygons and inserted for assessing classification accuracy. The pixels were counted within each site and the classification matching was shown in an error matrix (Table 2).

3.2. Changes in forest area

The total area of forests was 7,464 ha in 1965 and increased to 10,030 ha in 2003 (Table 3). These figures reveal that the total area of forest expanded during the 38-year period covered in this study. Forests in 2003 included 6,207 ha of new growth or regeneration outside of the older forest patches that existed in 1965, with 80% of the new patches located within 500 m of the older forest limits (Fig. 7). The number of the outer forest patches has sharply increased within the first 500 m gauging from the edge of the older forest patches. Surpassing the 500 m distance, the number of patches changes to an asymptotic form with minimal values. Proximity to older forest patches appears to encourage regeneration. This highlights the importance of connectivity and the relationship between remaining forests and regenerated ones.

During the study period (38 years), older forests decreased in area by 3642 ha (Fig. 8). None of the 1965 forest patches retained its full area in 2003. Only one single patch showed 92% of remaining forest area on the inside in 2003. This reveals that every forest patch that existed in 1965 has undergone major changes. Six patches had kept a forest area of between 80% and 86% by 2003. Forest cover inside the older forest patches decreased dramatically with the expansion of agricultural and urban areas.

The majority of the 1965 forest patches were clear forests, with a loss of 55% of their forests (Table 3), whereas dense forest patches showed a 38% decrease in the exited forest area in 1965.

The permanent changes in forest area were the places that have changed to urban areas and quarries (Photo 1a). These replaced 4% of the 1965 forest patches. The majority of urban areas and quarries were found on the outside of the older forest patches. The temporary forest changes were found to be due to agriculture, grasslands and water which replaced about 30%, 13.4% and 0.5% respectively of the 1965 forests.

Despite the overall loss of the forests, certain zones were totally conserved, as attested to by the fact that 18% of clear forests in 1965 had become dense by 2003. Rainwater reservoirs that were found only in clear forests encouraged the replacement of forest by cultivation (Photo 1b).

3.3. Landscape indices in 1965 compared with forest loss in 2003

Further investigations based on landscape indices are required to determine the mechanism of expansion of older forest and the appearance of new forests. Forest loss shows no correlation with the original patch shape calculated in 1965 (Fig. 9). The MPFD, which ranges between 1.23 and 1.43, demonstrates simple to relatively complex patch shapes. The 4 patches that have MPFD of above 1.40 showed a high level of forest loss and they retained less than 40% forests. However, the relation between patch shape (MPFD) and forest loss remains unclear because of the low patch numbers that have complex shapes (MPFD above 1.40). Patch size, on the other hand, shows a certain degree of correlation with a correlation coefficient of 0.86 (Fig. 10). The forest patches of 1965, which had less than 40 ha in size (small patches), showed either important forest loss or minor forest loss in 2003. About half of those patches have kept above 50 % forest

cover; the third of the same forest size patches had lost more than 80% of their original forest cover by the year 2003. Whereas, larger forest patches of 1965, i.e. between 40 and 200 ha in size, showed lower percentage of forest loss by the year 2003 where this forest loss did not reach the 20%. They retained a certain degree of forest cover that is between 20 and 78%. About 40% of the patches of this size range (40 to 200 ha) had preserved forest cover of higher than 50%. The patches that have a size of more than 200 ha had maintained more than 50% of their forest cover. Dense canopy closure forest patches kept more than 50% forest cover in all three patch size ranges (less than 40 ha, between 40 and 200 ha, and more than 200 ha).

4. Discussion

Using landscape indices, we analyzed changes in Eastern Mediterranean oak forests during a 38-year period. Comparison of 1965 and 2003 forests enabled us to discriminate new from existing forests. Landcover types in 2003 that replaced older forests are another key to understanding the forest loss processes.

The 1965 forest map was the base forest data used in this study. The accuracy of this map was significant for further analysis. Visual comparison was performed between the forest patches on the map and on the aerial photos that were used to create the forest map of 1965. Each forest patch (polygon in GIS layer) delineated woods on the aerial photos. Since the whole set of the aerial photos is not available, half of the patches were verified for matching their edges with the underlying woods on the aerial photos. Visual interpretation of the map quality was similar to digitizing accuracy performed in GIS. It

is critical to test the quality of production of an existing map before using it for any assessment.

The accuracy of the classification of satellite imagery was obtained using ground truthing. It is helpful in the classification of the image and to collect ground truth to have the printout of the image on site. Many features on the image might be classified during field survey. The false color composite used in the image printout enabled us to distinguish between different features especially vegetation types. The tone of the red color showed variability between different canopy closures of vegetation. The ground truth points were changed into areas using this verification approach.

If we had only compared the changes in the total forest area, the forests' spatial variations and exact distribution would have remained unidentified. However, the inside and outside patch analysis enlightened the understanding of spatial forest changes. The 1965 forest patches showed significant loss in forest area while regrowth has appeared on the outside of these forest patches. The percent forest area loss was determined for each 1965 forest patch. This forest loss was compared to the spatial characteristics of the patch that existed in 1965.

The risk of forest loss was tested for its possible relation to patch size, patch shape, canopy closure, and edge distances. Temporal forest changes did not show correlation with patch shape, possibly because most of the older patches had a similar degree of shape complexity. In contrast, forest loss does correlate with patch size and canopy closure. Small patches (<40 ha) of clear forest were easily degraded and may disappear under external pressures (Fig. 9). This trend is related to the fact that small patches are easily replaced by agriculture and other human activities. As indicated in previous

literatures, a smaller patch size is a sign of frequent disturbances and possible degradation risk (Pearson et al., 1998). In contrast, large forest patches of more than 40 ha are highly resistant to disturbances.

Forest area loss of the 1965 forests was considered permanent if landuse had changed to urban areas and quarries. Quarries require land rehabilitation before considering any forest regrowth. Forests that were changed to urban landuse require major interventions and special measures to establish regeneration. Temporary landcover changes of the 1965 forests were agriculture, grasslands and water. About 40% by area of the older forest patches was changed to agriculture and grasses, which might undergo future forest regeneration when abandoned.

Oak forests show high regeneration capability, as oak is highly adapted to environmental conditions of coastal Mediterranean regions (Mouterde, 1966; Salleo et al., 2002). Abandoned agricultural terraces, which retain water and nutrients, are sites of forest regeneration from existing (expansion) or juvenile forests (regeneration) (Photo 1c). As rainwater reservoirs are becoming more common throughout the study area, agricultural lands become the chief invader of older forests (Photo 1a).

Oak forests can almost reach a canopy closure of 100% when they grow in favorable conditions (field explorations). In 1965, only 38% of forest patches had dense canopy closure that might indicate a sign of previous forest destruction or might point out the presence of developed (dense canopy forests) and under development forest patches. While in 2003, 31% of the total forest area was dense forests, revealing continuous pressure over this forest for almost four decades. Oaks have been able to grow in harmony with urban settlements for many years, but they are unable to reach higher

canopy closure levels under such continuous pressure. Forests in the study area were oak coppice in both 1965 and 2003. *Pinus pinea* demonstrated limited growth in the study area, noting that it favors sandstone originated terrains which are rarely present within the study area (Abi Saleh, 1978). Stands of *Pinus pinea* are widespread in other places throughout Lebanon and they are mostly cultivated on sandstones.

Logging of trees for charcoal production has the potential to rapidly and completely change the landcover pattern (Photo 1d). This type of logging is a major source of disturbance in the study area, as is the case in many natural Mediterranean ecosystems (Farina, 1998; Talhouk et al., 2001; Jomaa and Bou Kheir, 2003). Oak forests would be highly resistant to human pressure associated with agriculture and cutting if their ability to regenerate was ensured.

Changes in forest ecosystem in the Western Mediterranean have been thoroughly considered in the literature (Barbero et al., 1990). Such studies have found that socioeconomic changes throughout the 19th century led to the abandonment of agricultural land, while other areas experienced an intensification of agriculture (Baudry and Tatoni, 1993). The pattern of agriculture in the Eastern Mediterranean reveals that deforestation has created a patchy landscape; at the same time the abandonment of agricultural lands caused forests to recover.

A more comprehensive analysis of such landscapes is possible by covering larger areas and using multitemporal satellite images. Landscape indices, which are mostly applied to subtropical forests, should be more applied to Mediterranean landscapes, in order to obtain a comprehensive view of their possible applicability in such environmental zones.

As has been demonstrated for tropical environments (e.g., Matsushita et.al., 2005), study methods involving high performance adapted landscape indices and sophisticated monitoring on a patch basis are crucial to preserve Mediterranean forests. Mediterranean forests have been subjected to severe destruction and degradation mainly because of human interventions. Restoration and conservation practices cannot be implemented in a sustainable manner without a better understanding of the dynamics of forest ecosystems.

able 1. Forest types in 1965, as determined by El Hussein and Baltax (1965).

| # | Forest type | Surface coverage (%) | Canopy closure (%) | | Species composition |
|---|-------------|----------------------|--|---------------|--|
| 1 | Oak coppice | 96 | >30 | Dense forests | <i>Quercus calliprinos</i> , <i>Quercus infectoria</i> , with or without some <i>Pinus brutia</i> , <i>Juniperus</i> and <i>maquis</i> spp in varying portions |
| | | | 10 to 30 | Clear forests | |
| 2 | Cedar | 1 | >40 | | <i>Cedrus libanin</i> with or without <i>Quercus</i> spp, <i>Juniperus</i> spp., and <i>Abies silica</i> , in varying portions |
| | | | 10 to 40 | | |
| 3 | Cypress | 3 | Small isolated occurrence denoted by small circle like shape | | <i>Cupressus sempervirens</i> usually in mixture with <i>Pinus. brutia</i> |

Table 2. Error matrix of the satellite image classification.

| | | Ground truth | | | | | | |
|---------------------------------|--------------|---------------|---------------|---------------|---------------|-------------|-------------|-------------|
| | | Clear forest | Dense forest | Agriculture | Grass | Urban | Quarry | Water |
| Classified image | Clear forest | 23,511 | 951 | 1737 | 460 | 243 | 174 | 14 |
| | Dense forest | 1144 | 97,376 | 1186 | 752 | 490 | 231 | 23 |
| | Agriculture | 1245 | 892 | 55,188 | 709 | 640 | 256 | 29 |
| | Grass | 762 | 294 | 414 | 40,948 | 568 | 44 | 11 |
| | Urban | 134 | 853 | 810 | 502 | 8689 | 63 | 7 |
| | Quarry | 489 | 415 | 656 | 547 | 94 | 5490 | 3 |
| | Water | 3 | 10 | 28 | 11 | 7 | 5 | 1526 |
| Total | | 27,288 | 100,790 | 60,017 | 43,928 | 10,729 | 6262 | 1613 |
| Correctly classified pixels (%) | | 86.2 | 96.6 | 92.0 | 93.2 | 81.0 | 87.7 | 94.6 |

Table 3. Forest changes between 1965 and 2003.

| | | 2003 | 2003 | Total (ha) |
|--------------------|---|---|---|------------|
| Landcover types | 2003 landcover outside 1965 forest patches (ha) | Landcover within 1965 clear forest patches (ha) | Landcover within 1965 dense forest patches (ha) | |
| 2003 landcover map | Clear forests | 4877 | 813 | 6929 |
| | Dense forests | 1330 | 960 | 3101 |
| | Agriculture | 18,877 | 762 | 21,171 |
| | Grass | 8079 | 239 | 9083 |
| | Urban | 530 | 92 | 824 |
| | Quarry | 232.4 | 5 | 244 |
| | Water | 43 | 0 | 82 |
| Total (ha) | | 33,968 | 2871 | 41,433 |

Captions:

Fig. 1. Location and topography of the study area

Fig. 2. Example of forest map of 1965 (a); and Spot 5 satellite image (b).

Fig. 3. Forest canopy closure of >30% in (a); and of 10 to 30% in (b).

Fig. 4. Landover map for 2003 constructed by classifying a Spot 5 satellite image.

Fig. 5. Visual comparison between forest map of 1965 and the aerial photos of 1962.

Fig. 6. Comparison between an aerial photo used for the 1965 forest map and the SPOT 5 satellite image (color composition: R = green band, G = red band and B = near infrared band).

Fig. 7. Edge distance between newly emergent forests in 2003 and 1965 forest patches.

Fig. 8. Spatial forest changes between 1965 and 2003.

Fig. 9. Forest area remained in 2003 inside the 1965 forest patches vs the patch shapes of 1965 forests.

Fig. 10. Relationship between forest loss and patch size in 1965 forest map.

Photo 1. a) Rainwater reservoirs between forests have aided the expansion of agricultural land. **b)** Quarries within forests. **c)** Abandoned agricultural terraces covered in early stages of regeneration forest. **d)** Forest being logged for charcoal production.

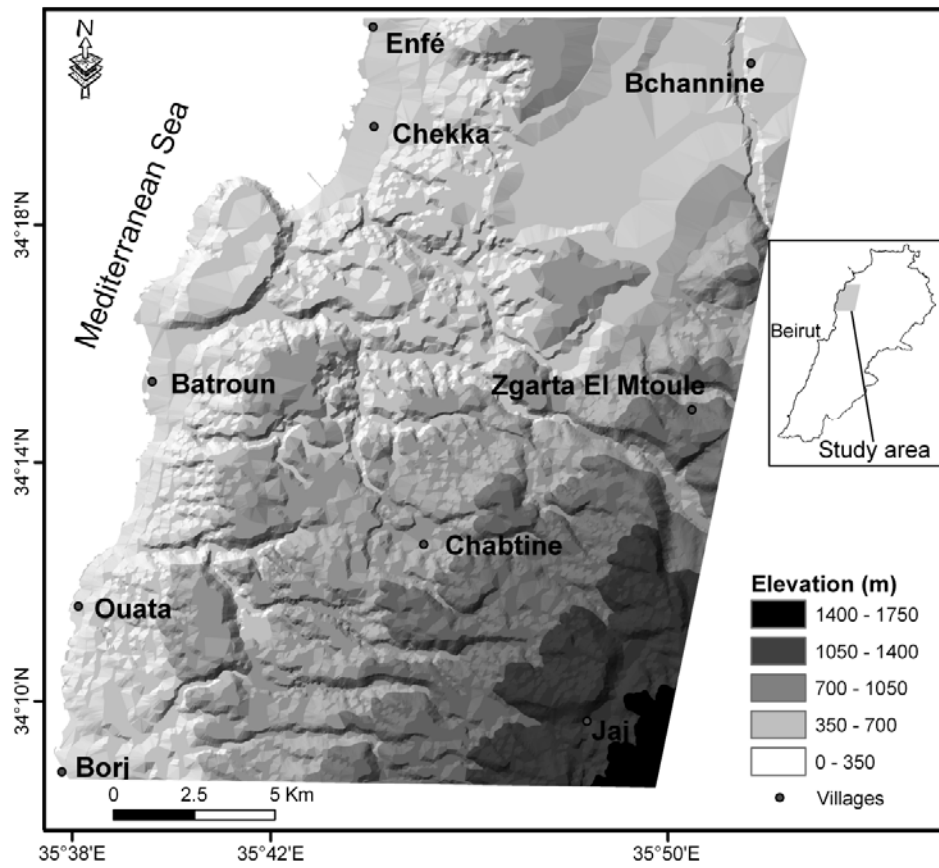


Fig. 1. Location and topography of the study area

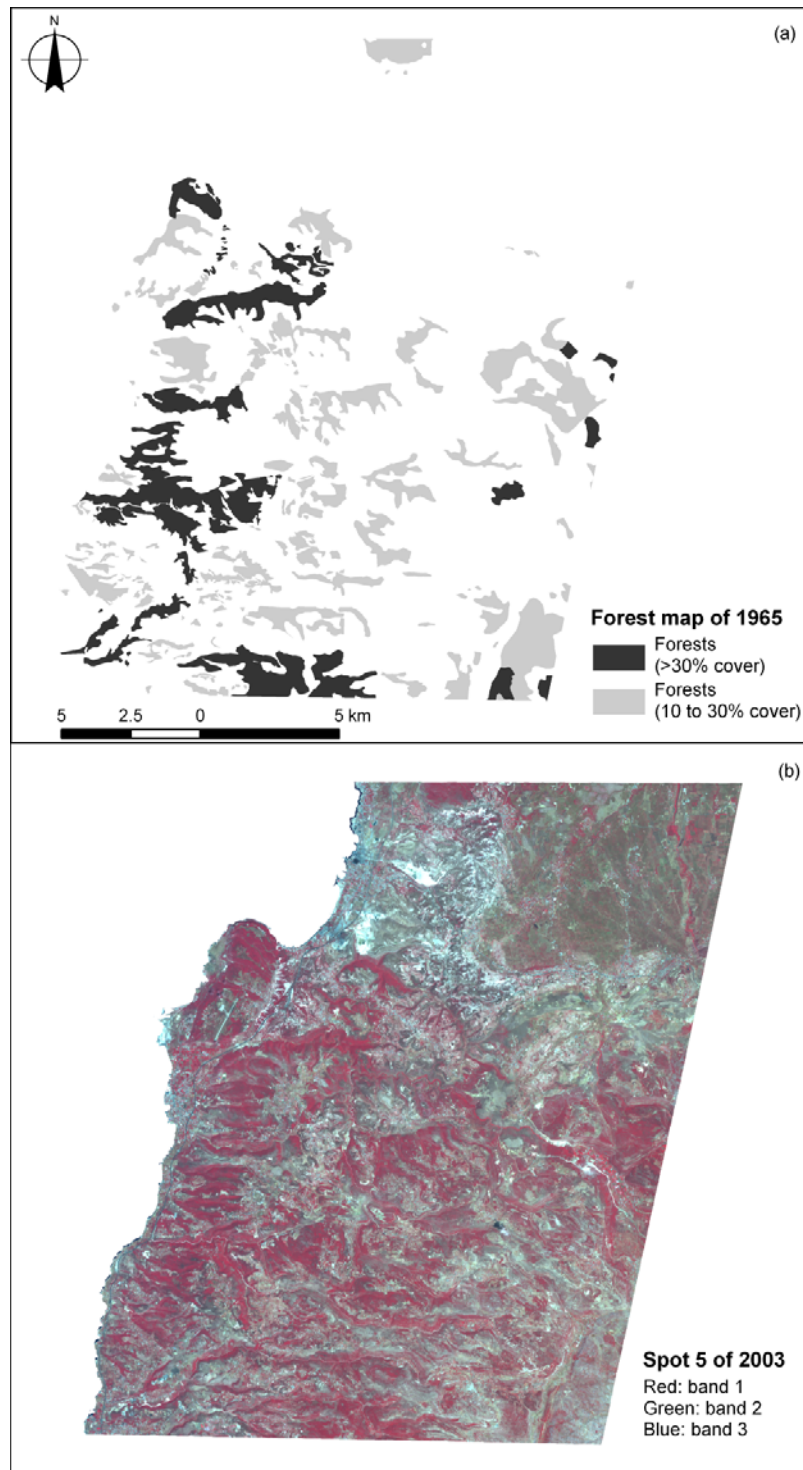


Fig. 2. Example of forest map of 1965 (a); and Spot 5 satellite image (b).

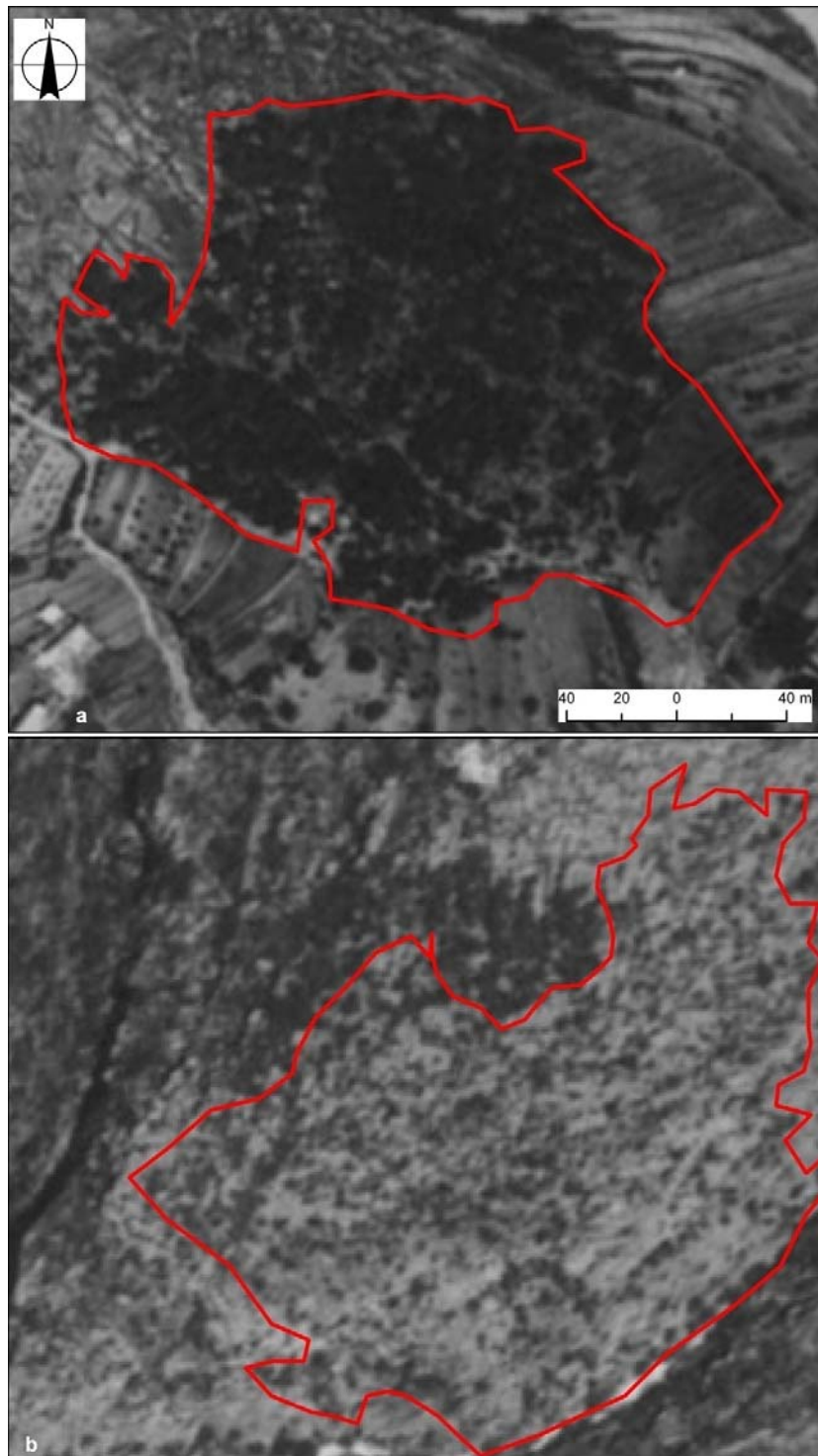


Fig. 3. Forest canopy closure of >30% in (a); and of 10 to 30% in (b).

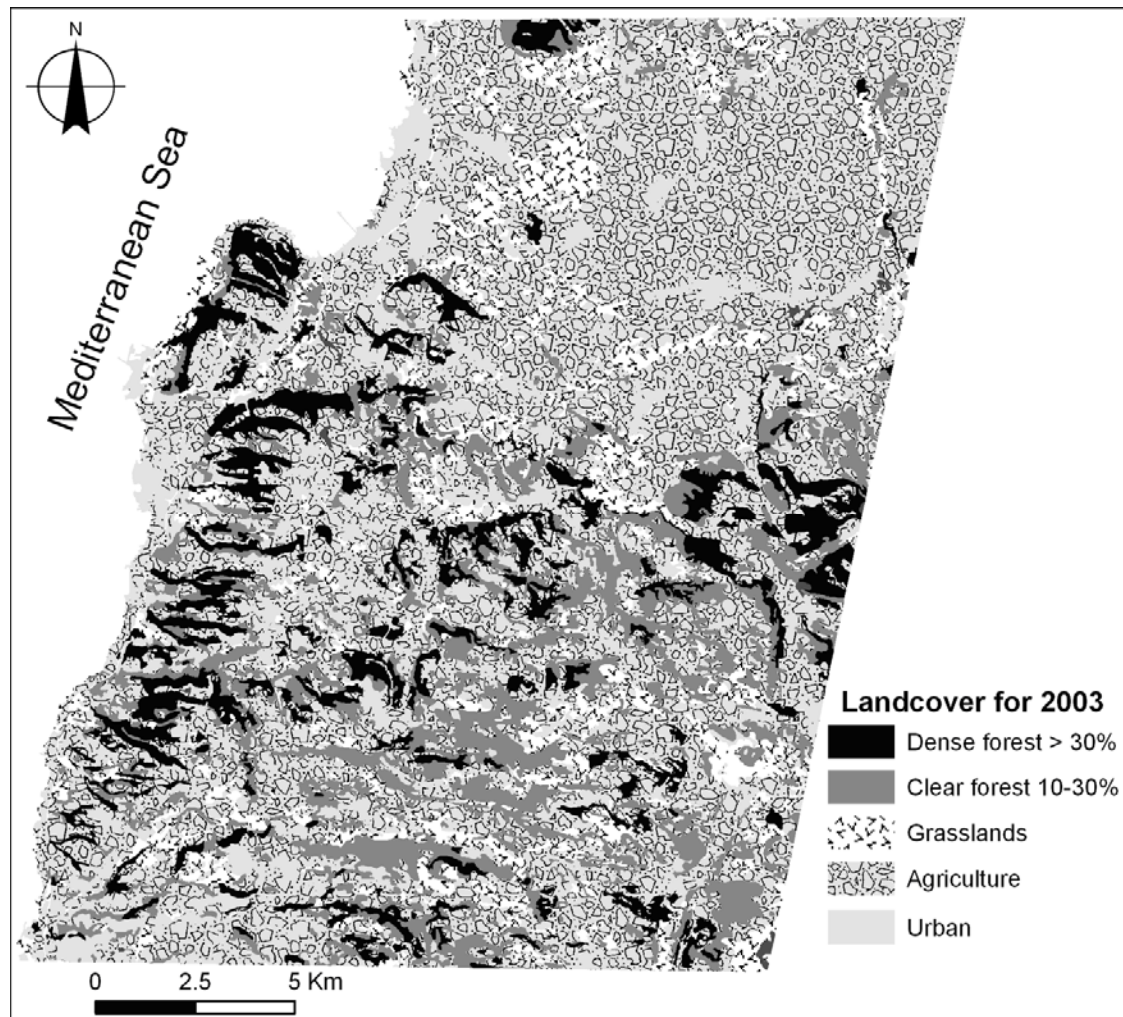


Fig. 4. Landover map for 2003 constructed by classifying a Spot 5 satellite image.

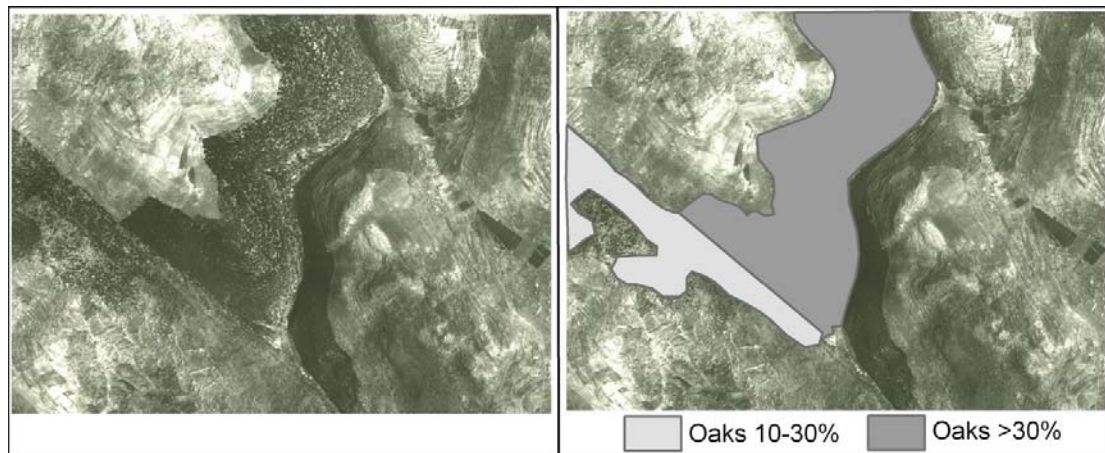


Fig. 6. Comparison between an aerial photo used for the 1965 forest map and the SPOT 5 satellite image (color composition: R = green band, G = red band and B = near infrared band).

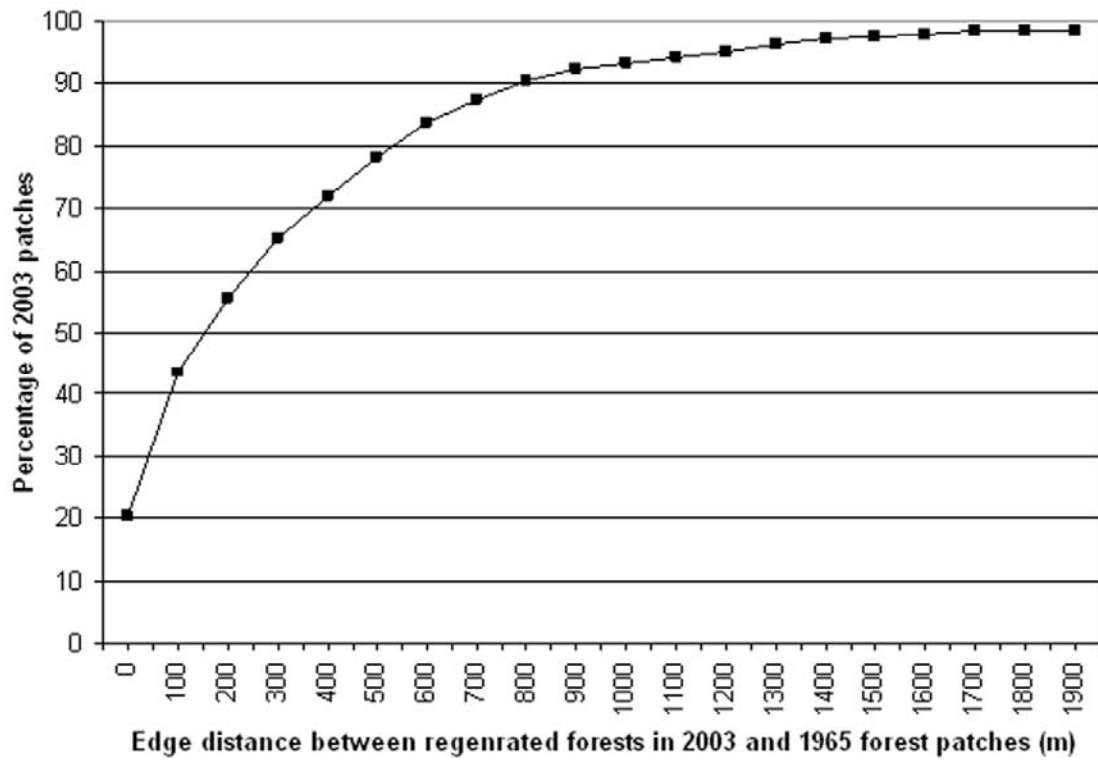


Fig. 7. Edge distance between newly emergent forests in 2003 and 1965 forest patches.

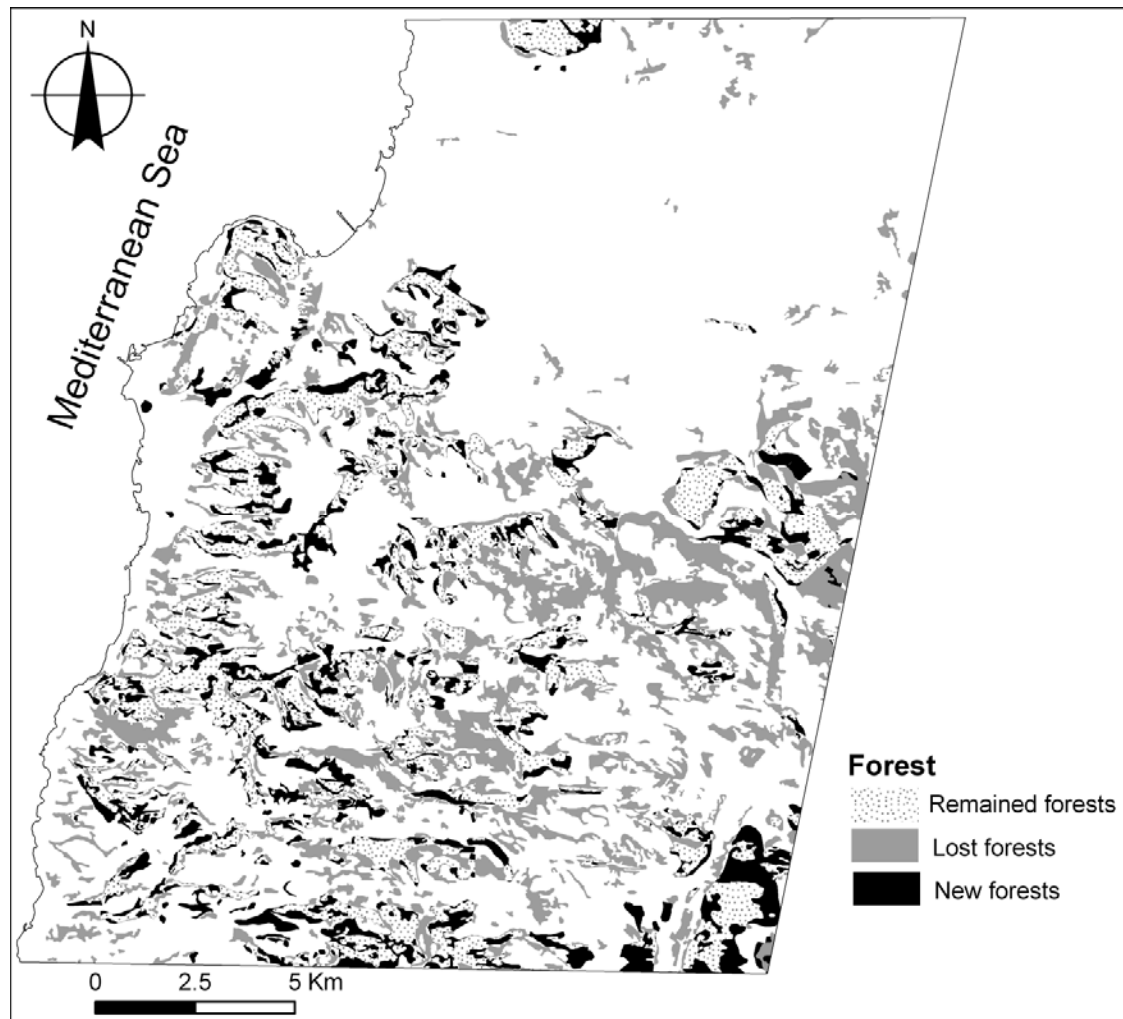


Fig. 8. Spatial forest changes between 1965 and 2003.

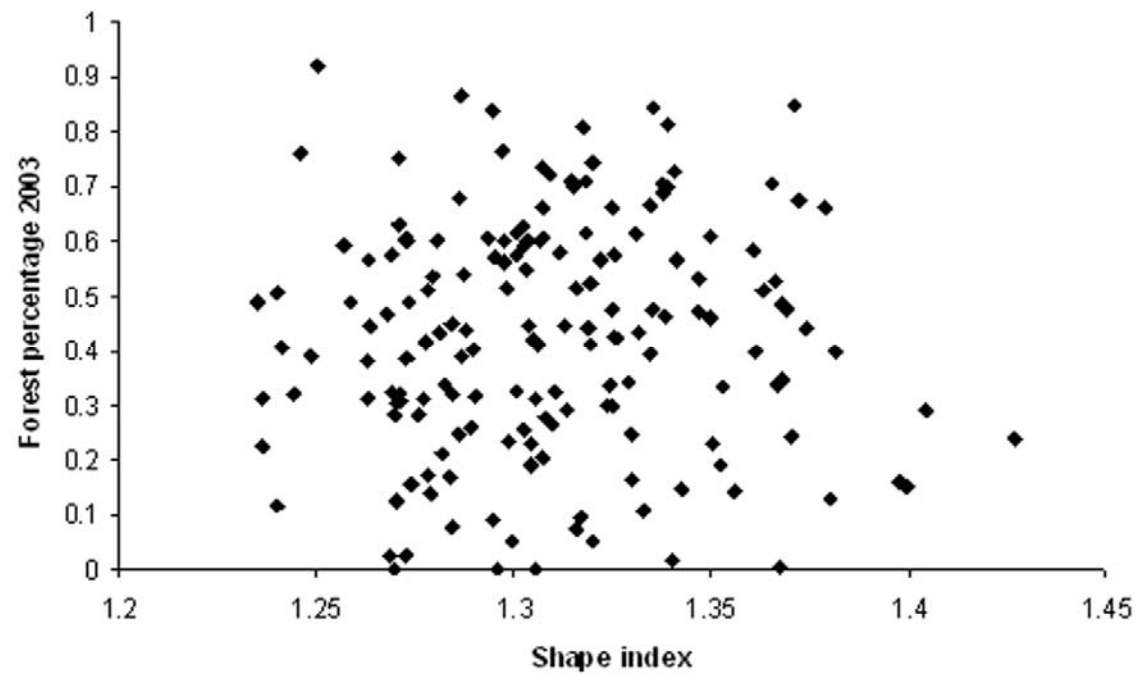


Fig. 9. Forest area remained in 2003 inside the 1965 forest patches vs the patch shapes of 1965 forests.

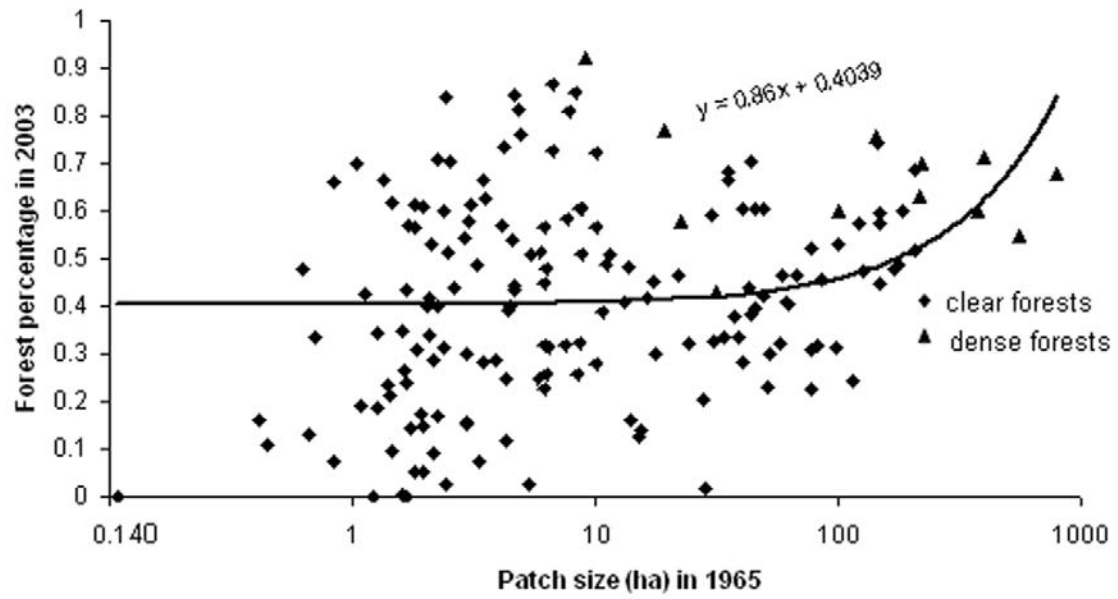


Fig. 10. Relationship between forest loss and patch size in 1965 forest map.

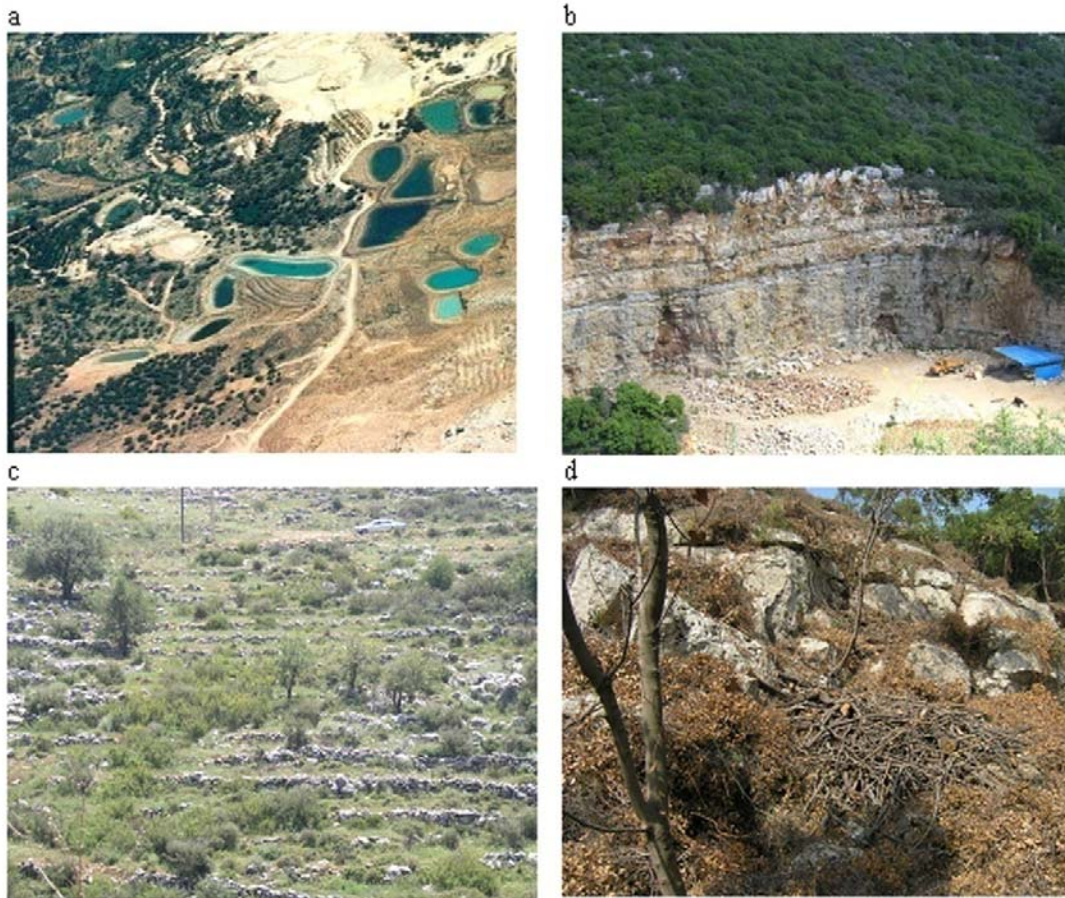


Photo 1. a) Rainwater reservoirs between forests have aided the expansion of agricultural land. b) Quarries within forests. c) Abandoned agricultural terraces covered in early stages of regeneration forest. d) Forest being logged for charcoal production.

Article 4.

I propose this report-like article to be submitted as a report to Lebanese Science Journal.

Nécessité d’harmonisation des données provenant de cartes forestières libanaises “anciennes”

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RÉSUMÉ

L'étude de la répartition et de l'évolution des écosystèmes forestiers libanais nécessite l'obtention de données à partir des cartes topographique et forestière "anciennes". Evaluer la précision et la fiabilité de ces documents est nécessaire préalablement à leur utilisation.

Bien que les deux cartes dérivent de la même source, i.e. photos aériennes de l'année 1962, des différences dans les légendes et les délimitations spatiales des polygones sont observées. Ces divergences sont dues à:

- 1. la différence de description des polygones, e.g. les parcelles désignées comme "bois et broussailles" sur la carte topographique sont plus détaillées sur la carte forestière;*
- 2. une variabilité de la délimitation des polygones d'où des discordances dans la superficie du couvert végétal;*
- 3. l'absence de certains polygones sur la carte forestière tandis qu'ils figurent sur la carte topographique.*
- 4. une délimitation différente des bordures de parcelles relativement contiguës.*

Il est alors obligatoire d'harmoniser les légendes mais encore de définir les polygones (contour et identité) spécialement pour les zones litigieuses. Nous avons donc, à l'aide d'un SIG, comparé ces cartes à une image satellitale (SPOT 5, 2003). Les résultats, renforcés par d'anciennes et de récentes données de terrain, sont transcrits sous la forme d'une carte forestière, dérivée de celle de 1965; elle comporte une légende harmonisée et montre une distribution plus complète de la végétation. La nouvelle carte est le document de base pour une étude de la biodiversité des paysages libanais. Cette méthodologie pourrait être appliquée où des cas semblables sont rencontrés.

ABSTRACT

In order to define and monitor changes in northern Lebanese forest ecosystems, we had to gather data from "ancient" topographic and forest maps. Weighting the degree of accuracy and reliability upon such "historical" documents is a must before any use of these data.

Even though both maps derived from the analysis of the same source, i.e. the aerial photos of 1962, differences in the legends as well as in the spatial delineation of forest patches were observed. These mismatchings are due to:

- 1. a difference in the description of the polygons, e.g. patches categorized as "woods and shrubs" on the topographic map are more detailed on the forest map;*
- 2. a variability in polygon contours for some similar patches, which leads to different surface areas of vegetation cover;*
- 3. an absence of some polygons on the forest map whereas they appear on the topographic map;*
- 4. different delineation of the extent of relatively contiguous forest patches.*

It is then mandatory to harmonize the legends but also to define exactly the polygons (contour and identity) especially where mismatching was noticed. In order to do so these maps were compared, using GIS, to a satellite image (SPOT 5, 2003). The results, reinforced by old and recent field data, lead to the establishment of a derived 1965 forest map. This latter is based on a harmonized legend and contains more comprehensive vegetation distribution, which was our goal. The outcome is used as a base map for a landscape biodiversity study. This methodology could be applied where similar cases are encountered.

MOTS-CLÉS: Liban, cartes "anciennes", SIG, image satellitale.

KEYWORDS: Lebanon, "ancient" maps, GIS, satellite image.

1. Introduction

La flore du Liban a fait l'objet de nombreuses études. Parmi les premières récoltes floristiques figure celle de Houton De Labillardière (1791) qui séjourna entre la Syrie (Damas, Hermon) et le Liban. L'ouvrage le plus connu est la "Nouvelle Flore du Liban et de la Syrie" (Mouterde, 1966). Suivirent ensuite un ensemble de travaux floristiques améliorant notablement la connaissance de la flore et de la végétation libanaises, notamment (Pabot, 1959; Abi Saleh, 1978; El-Habre et El-Habre, 1993; El-Habre et El-Habre, 1996; Tohmé Tohmé, 2001).

La plus ancienne carte à grande échelle (1/50 000) est une carte topographique éditée en 1963 par la Direction des Affaires Géographiques et Géodésique (DAGG, 1963). Elle repose sur l'interprétation de photographies aériennes acquises en 1962 et contient quelques éléments décrivant les formations arborées. En 1965 une première carte forestière, dressée elle aussi au 1/50 000, est publiée par El Husseini et Baltaxe (1965); elle est basée sur la même couverture aérienne et décrit précisément les formations forestières décomposées en huit types (Tableau 1).

Baltaxe (1966) reprend cette carte en ajoutant des données relatives aux compositions spécifiques mais en réduisant l'échelle au 1/200 000. La "Carte de la végétation du Liban" (Abi Saleh et Safi, 1988) améliore l'information floristique en apportant des précisions phytosociologiques et phytoécologiques sur les étages et séries de végétation du Liban.

Dans les années 1990 une avancée technologique, la télédétection spatiale, est à l'origine d'une cartographie d'occupation du sol du Liban. La FAO (Food and Agricultural Organization) produit en 1990 (FAO, 1990) une carte au 1/50 000 à partir d'images Landsat TM acquises en 1987. Sur cette carte, les forêts sont assez peu détaillées et seules quelques formations arborées sont distinguées : conifères, feuillus, buissons et quelques types de formations dégradées.

En 2002, les ministères libanais de l'Agriculture et de l'Environnement réalisaient la carte du Mode d'Occupation du Sol (MOS, 2002) à partir d'une image IRS (Indian Remote Sensing Satellite) panchromatique et d'une image Landsat TM, toutes deux acquises en 1998. Les formations arborées y sont représentées par 18 types, différenciant par leur nature et l'importance de leur recouvrement du sol, e.g. forêt dense, forêt mixte clairsemée, Quercus spp. clairsemé, etc.

Dans le cadre de notre projet axé sur la dégradation des forêts du Liban, la carte El Husseini et Baltaxe (1965) constitue la source initiale d'information. Les premiers efforts portent sur l'estimation de la qualité géométrique et thématique de cette carte. La démarche retenue consiste en une analyse historique où la confrontation de sources cartographiques et bibliographiques, ainsi que des contrôles réalisés sur le terrain, en constituent les bases méthodologiques.

2. Méthodologie

La zone d'étude (*figure 1*) s'étend de la côte libanaise jusqu'à la plaine de la Bekaa en traversant la chaîne du Mont-Liban ; sa superficie est de 1409 km², soit 13.5% de la surface du pays. Cette zone comprend presque la totalité des étages bioclimatiques et des étages de végétation présents au Liban (Abi Saleh *et al.*, 1996).

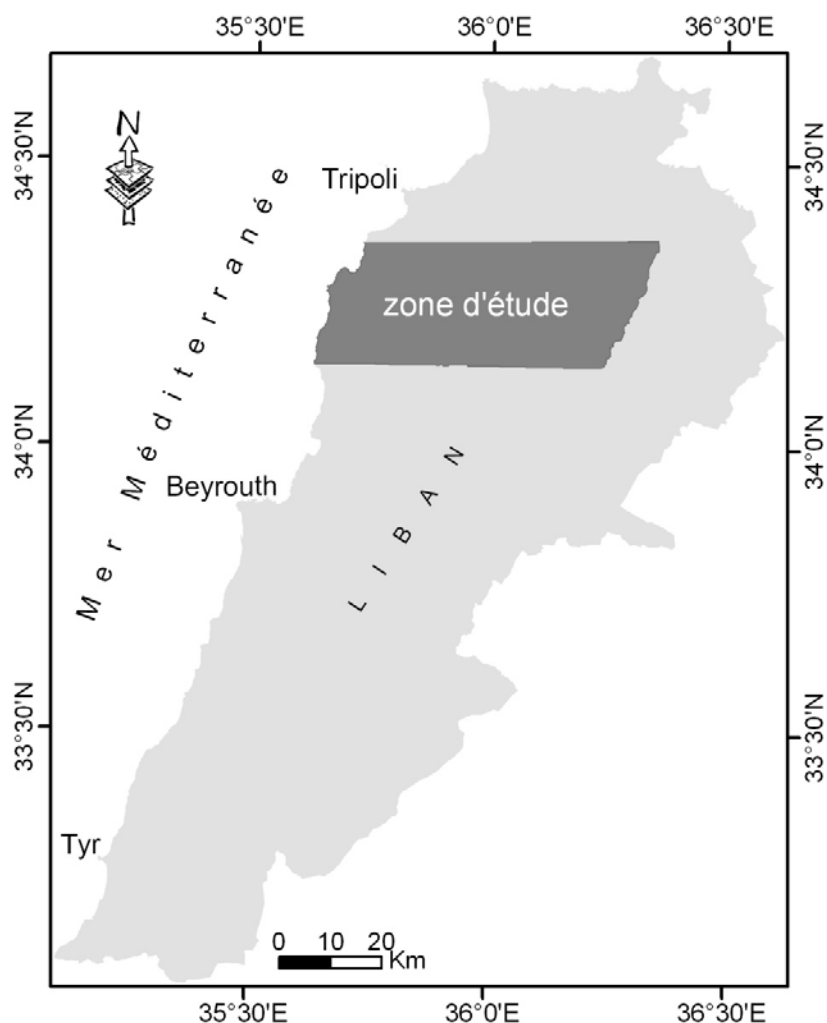


Figure 1. Localisation de la zone d'étude.

La méthodologie vise à estimer le plus précisément possible la qualité géométrique (spatiale) et thématique de la carte forestière (El Hussein et Baltaxe, 1965) par recoupement avec les autres sources d'information possédées. Elle comprend quatre étapes: 1) Conversion des cartes (support papier) forestière (El Hussein et Baltaxe, 1965) et topographique (DAGG, 1963) dans un format numérique géoréférencé, 2) Comparaison de ces deux cartes, 3) Analyse de 2 scènes de l'image Spot 5 (2003) relative à la zone d'étude, couplée à une "vérité terrain", 4) Établissement d'une carte forestière homogénéisée, dérivée de la carte forestière de 1965.

2.1. Conversion des cartes (support papier) dans un format numérique géoréférencé.

Huit feuilles de la carte forestière (El Hussein et Baltaxe, 1965) couvrent la zone d'étude. Le géoréférencement de chacune d'elles est effectué à partir du carroyage "Lambert Conformal Conic" utilisé au Liban. La délimitation des formations forestières a été ensuite digitalisée sur écran.

Notons qu'un certain nombre de zones figurant sur cette carte sont entourées par un trait pointillé, sans indication précise sur la limite, la subdivision et la nature de ces formations. Nous reviendrons par la suite sur ce manque de données et sur la façon de le traiter.

Les feuilles de la carte topographique du Liban recouvrant notre zone d'étude ont le même référentiel que celles de la carte forestière. Elles sont intégrées au SIG par une procédure rigoureusement identique à la précédente (géoréférencement et digitalisation).

2.2. Comparaison des cartes numériques géoréférencées

La légende de la carte forestière (El Husseini et Baltaxe, 1965) montre plus d'information sur les catégories identifiées que celle de la carte topographique (DAGG, 1963). Sur cette dernière, les zones arborées se résument à bois/broussailles (*figure 2*) tandis que la carte forestière comporte 16 catégories, tenant compte du degré de recouvrement des différentes formations forestières (*tableau 1*).

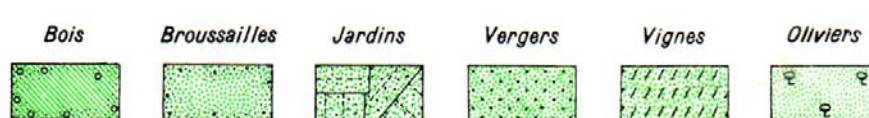


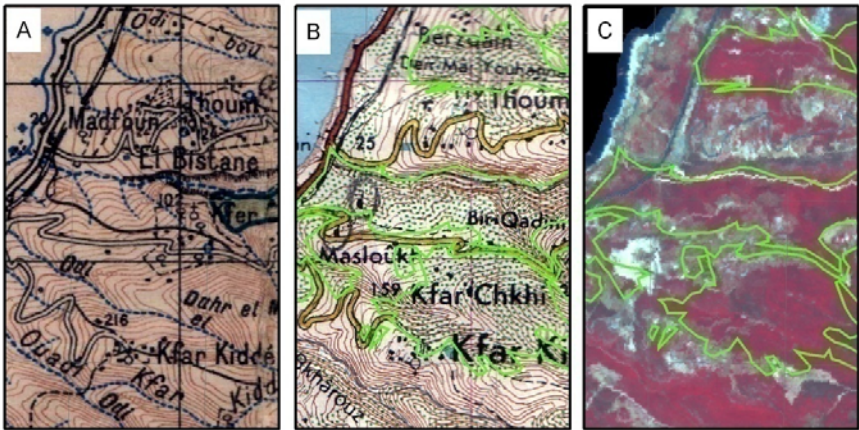
Figure 2. Extrait de la légende de la carte topographique (DAGG, 1963).

| # | Type de forêt | Recouvrement (%) | Espèces |
|---|---------------------|---|---|
| 1 | Taillis de chêne | >30 | <i>Quercus calliprinos</i> , <i>Q. infectoria</i> , avec ou sans quelque <i>Pinus brutia</i> , <i>Juniperus</i> et <i>maquis</i> spp en proportions variées |
| | | 10-30 | |
| 2 | Chêne | >30 | <i>Quercus calliprinos</i> , <i>Q. infectoria</i> , <i>Q. brantii</i> , <i>Q. cerris</i> |
| | | 10-30 | |
| 3 | <i>Pinus brutia</i> | régénération ou implantation ponctuelle | |
| | | >40 | <i>Rarely Pinus halepensis</i> |
| 4 | <i>Pinus pinea</i> | 10-40 | |
| | | régénération ou implantation ponctuelle | - |
| 5 | cèdre | >40 | <i>Cedrus libanin</i> avec ou sans <i>Q. spp</i> , <i>Juniperus spp.</i> , et <i>Abies silica</i> , en proportions variées |
| | | 10-40 | |
| 6 | sapin | >40 | <i>Abies cilica</i> et <i>Juniperus spp.</i> Avec ou sans <i>Cedrus libani</i> , <i>P. brutia</i> , and <i>Q. spp.</i> , en proportions variées |
| | | 10-40 | |

| | | | |
|---|-----------|--|--|
| | | >30 | <i>Juniperus excelsa</i> , <i>J. foetidissima</i> , avec ou sans <i>Quercus calliprinos</i> et <i>Q. infectoria</i> en proportions variées |
| 7 | genévrier | 10-30 | |
| 8 | cyprès | petite formation isolée, présence indiquée par de petits cercles | <i>Cupressus sempervirens</i> habituellement associé à <i>P. brutia</i> |

Tableau 1. Thèmes portés sur la carte forestière (El Hussein et Baltaxe, 1965).

D'autre part, la superposition des deux cartes montre qu'un plus grand nombre de zones arborées sont présentes sur la carte topographique. La délimitation de ces zones est également beaucoup plus précise (figure 3). Les zones limitées en pointillé sur la carte forestières entourent des polygones qui sont considérés non cartographiables, tandis que ces mêmes polygones sont décrits avec précision sur la carte topographique (figure 4).



Report des contours (bois et broussaille) de la carte topographique sur l'image Spot

Figure 3. Comparaison sur un extrait de la carte forestière (A) à celle topographique (B). L'image satellite Spot 5 de 2003 (C) aide à la validation des résultats.

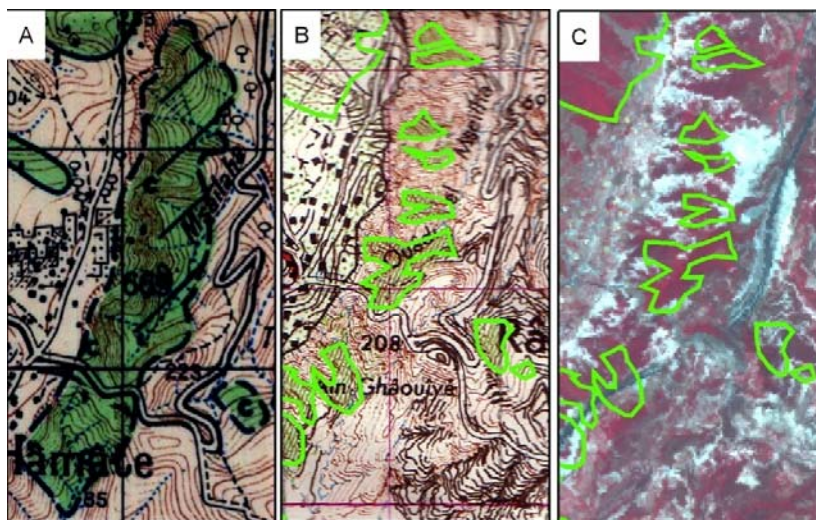


Figure 4. Les zones limitées en pointillé sur la carte forestières (A). Bien décrits avec précision sur la carte topographique (B). Coïncident avec l'image satellitale (C).

Trois éléments essentiels, avérés par le croisement de toutes les sources d'information à notre disposition, justifient la nécessité de l'évaluation de la qualité géométrique et thématique de tels documents: 1) la thématique des cartes est différente, celle de la carte forestière étant la plus complète; 2) la délimitation spatiale sur la carte topographique est meilleure; 3) un manque relatif d'informations sur la carte forestière – absence de la représentation des bois/broussailles sur la plupart des feuilles, lacune qui est cependant inversée sur les feuilles de “Hermel”.

2.3. Analyse d'image satellitale et vérité terrain

La carte forestière (El Husseini et Baltaxe, 1965) et la carte topographique (DAGG, 1963) utilisent comme source la même couverture aérienne réalisée en 1962. Il est noté dans la légende de la carte forestière qu'elle a été éditée en 1965 mais préparée par des missions de terrain en 1963 et 1964. L'écart de date de réalisation de ces deux cartes, de l'ordre d'une année, ne peut expliquer les grandes différences d'occupation du sol que nous avons observées. Elles ne peuvent donc être dues qu'à des différences de photo-interprétation liées aux objectifs des services qui les ont réalisées. Les topographes enregistrent toute donnée observée, et accessoirement la nature des espèces. Les forestiers possèdent une logique d'aménagement et d'exploitation de la forêt; ils s'intéressent plutôt à la caractérisation floristique des zones arborées en négligeant les broussailles et les garrigues.

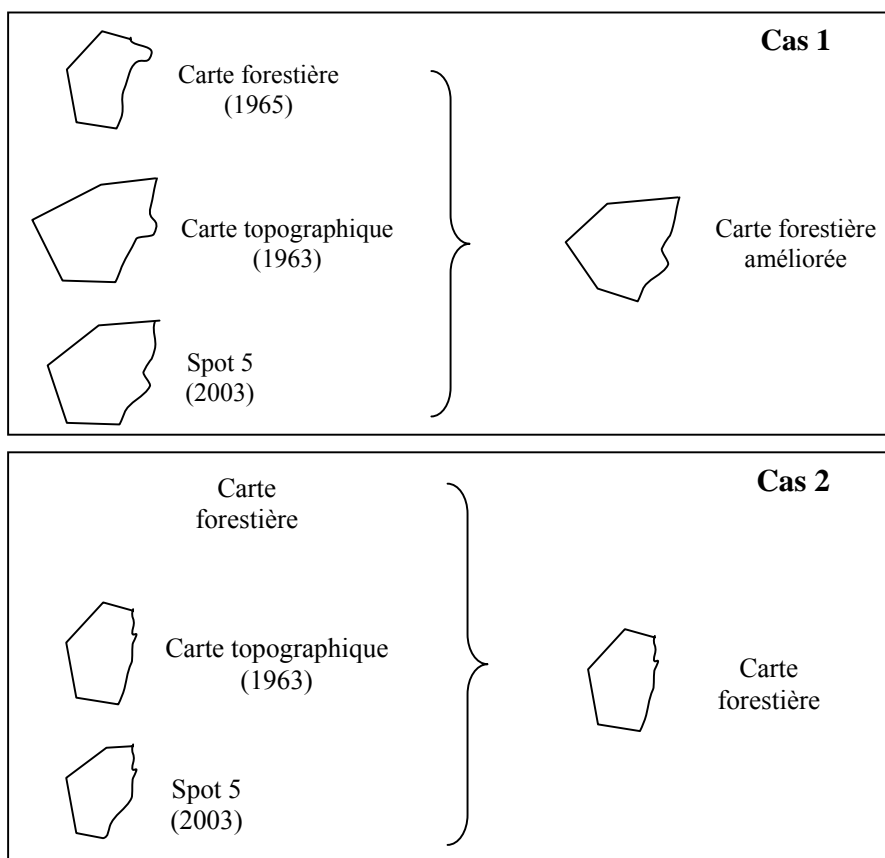
Pour déterminer avec encore plus de précision la délimitation antérieure et la nature des zones forestières, un croisement des données datant des années 60 est réalisé avec des données récentes dérivant de deux scènes d'une image satellitale (SPOT 5, résolution 10 m, 2003) ou collectées lors de plusieurs missions de terrain. Une telle approche nous a semblé plus efficace, plutôt que de reprendre une interprétation longue et fastidieuse par stéréoscopie de nombreuses photographies aériennes (plus de 150 couples photographiques couvrent la zone d'étude).

L'image satellitale est géoréférencée par reconnaissance de points d'amer communs avec la carte topographique. Le fort relief de la zone d'étude impose l'utilisation d'un polynôme de degré 2 lors de l'opération de recalage.

Une photo-interprétation visuelle de la composition colorée des trois premiers canaux Spot 5 (vert, rouge, proche infrarouge dans l'ordre RVB) suffit pour vérifier le bien fondé de la nécessité du croisement effectué. Dans plusieurs zones ayant peu évolué au cours de ces quarante dernières années, l'interprétation de l'image satellitale confirme que la précision géométrique (spatiale) des informations portées sur la carte topographique est meilleure que celle de la carte forestière. A l'intérieur des parties délimitées en pointillé sur la carte forestière, les limites des zones arborées coïncident avec celles de l'image satellitale (*figure 4*). Les missions effectuées sur le terrain précédemment (Abi Saleh, 1978) et actuellement confirment ces observations.

2.4. Carte forestière dérivée, à légende harmonisée

Afin de combler les lacunes cartographiques rencontrées, les corrections apportées ont été renseignées à partir de la carte topographique, et ceci selon la logique de la figure 5. Les cas de discordance relèvent des possibilités suivantes : 1. la carte forestière délimite les forêts avec des polygones plus réduits que celle de la carte topographique. 2. absence des délimitations sur la carte forestière. 3. délimitation des zones en pointillé sur la carte forestière (*figure 5*).



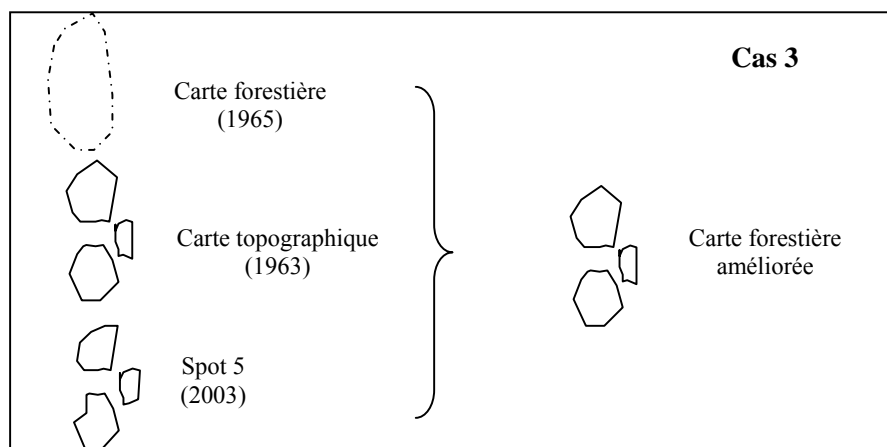


Figure 5. Méthode utilisée pour fusionner la carte forestière et la carte topographique.

L'analyse de l'image SPOT, renforcée par les résultats des investigations sur le terrain, nous a servi pour plus de confirmation spécialement dans les cas 2 et 3.

Quant à la légende adoptée, les informations portées sur la carte forestière sont celles qui ont été choisies.

Il en résulte une carte forestière, dérivée de celle de 1965, où les formations sont plus exhaustives et dont la légende est plus significative. Les surfaces en forêt de la zone d'étude sont estimées à 347 km² et à 307 km², respectivement d'après la carte forestière et la carte topographique. En prenant en considération toutes les formations forestières, y compris les broussailles, les formations arborées présentes sur la carte dérivée couvrent 388 km².

3. Conclusion

Travailler sur des données anciennes oblige à une analyse critique de leur fiabilité. Dans le cas de cartes, la précision géométrique des relevés et la qualité de la thématique doivent être bien évaluées. La méthodologie employée repose sur le croisement de sources anciennes et leur confrontation à des sources plus récentes. L'enregistrement dans un référentiel géographique commun et l'analyse comparée des différentes sources d'information sont rendus possibles grâce à un Système d'Information Géographique. L'intégration des données obtenues à partir de la composition colorée d'une image satellitale et des données de terrain sont également grandement facilitées.

Les résultats obtenus montrent la nécessité d'appliquer cette méthodologie à l'ensemble du territoire libanais pour mieux cerner les problèmes de l'étendue et de la distribution du couvert végétal. Les résultats concernant l'évolution de la forêt au cours des quarante dernières années fera l'objet de futures recherches.

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Bibliographie

- Abi Saleh B. Etude phytosociologique, phytodynamique et écologique des peuplements sylvatiques du Liban. Thèse Univ. Droit Econ. Sciences Aix-Marseille III 1978 ; 184 p.
- Abi Saleh B, Nasser N, Hanna R, Safi N, Safi S, Tohmé H. Etude de la diversité biologique du Liban. Ministère de l'Agriculture, Liban. PNUE. Projet GF/6105-92-72. 1996 ; publication No 3. pp. 146.
- Abi-Saleh B, Safi S. Carte de la végétation du Liban (1/2^{00.000}) avec sa notice explicative. *Ecologia Mediterranean*, XIV (1/2), 1988; 123-141.
- Baltaxe R. Forest map at 1/200,000 scale. Base on the 1/50,000 scale forest type map of Lebanon. Forestry Education, Training and Research Project, Green plan, Lebanon. United Nations Development Program-Special Fund/FAO 1966.
- DAGG, 1963. Topographic map at 1/50,000 (sheets of Batroun, Tripoli, Sir Ed Danieh, Hermel, Jbail, Qartaba, Baalbeck and Aarsal). Directory of Geographic and Geodesic Affairs, Lebanese Army.
- El-Habre M, El-Habre R. "Seven established Lebanese wildflowers not described among native flora", *Lebanese Science Bulletin*, (6) (1), 1993.
- El-Habre M, El-Habre R. "Five species, one subspecies and three varieties of wild flowers not reported among the flora of Lebanon", *Lebanese Science Bulletin*, 9 (1), 1996, p. 67-72.
- El Husseini K, Baltaxe R. Forest type map at 1/50,000 scale. Forestry Education, Training and Research Project, Green plan, Lebanon. United Nations Special Fund/FAO 1965.
- FAO. Carte d'occupation du sol à l'échelle de 1/50.000. 1990.
- MOS. Landcover map of Lebanon-obtained from 1998 satellite images. Prepared by the Lebanese National Council for Scientific Research (CNRS)-National Center for Remote Sensing with the collaboration of IAURIF (Institut d'Aménagement et d'Urbanisme de la Région d'Ile de France).LEDO program, UNDP. Ministry of Agriculture and Ministry of Environment (Lebanon). 2002.
- Mouterde P SJ. *Nouvelle Flore du Liban et de la Syrie*. Editions de L'imprimerie Catholique Beyrouth, vol. 1 de 3, 1966.
- Pabot H. Rapport au gouvernement du Liban sur la végétation sylvopastorale et son écologique. F.A.O., Rapport # 1126 Rome 1959.
- Tohmé G, Tohmé H. "Recherches sur le statut actuel de la flore du Liban". *Lebanese Science Journal*, 2 (1), 2001, 3-15.

Annex (Articles)

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